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**STORMWATER RUNOFF TREATMENT BY IMPOUNDMENT:
BARRHAVEN PILOT STUDY**

by

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REVIEW NOTICE

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ABSTRACT

This report presents the findings of a two-year study of stormwater runoff treatment by impoundment in an open basin. The treatment system was operated as a batch process for one summer and as a continuously overflowing pond for another. Runoff from 866 ha of agricultural and residential suburban lands partly under construction entered the treatment system.

Impoundment reduced pollutant loadings by over 90 percent for suspended solids, 75 percent to 90 percent for bacteria (total and fecal coliform and fecal streptococcus) and 25 percent to 50 percent for organic nitrogen and total phosphorus compounds when the runoff could be stored for more than 12 hours.

At least 5 mm of rainfall were required to produce measurable runoff. The ratio of runoff to rainfall was used to estimate the runoff volumes that would be generated by up to 25-year return frequency storms of one and two-hour durations. From this, a storage volume of 40 000 to 47 000 m³ was indicated, on the basis of containment of runoff from a ten-year storm. It was determined that the most effective method of operating the treatment system was to keep the reservoir drawn down to a shallow pond. When runoff entered the pond, the drain valve was closed and the treatment system filled. Where possible, the runoff volume would be contained until its quality was suitable for discharge. For runoff volumes exceeding the treatment system storage volume, discharge took place over the spillway with limited pollutant removal. When the effluent quality became satisfactory, the reservoir was drained to the original shallow pond, and dry weather flow allowed to pass through.

Other factors that govern the choice of treatment system storage volume are the runoff event frequency and the allowable discharge rate. It was found that of the approximately 30 events that could be expected from May to September about half took place within four days of one another. Allowing one day to fill and one day for storage, the reservoir should require two days to empty.

RÉSUMÉ

Ce rapport présente les conclusions d'une étude de deux ans qui a porté sur le traitement des eaux de ruissellement pluvial par décantation dans un bassin ouvert. Au cours d'un été, le bassin a été vidé périodiquement; pendant un autre, les eaux ont été accumulées et le trop-plein déversé à mesure. Les eaux provenaient du ruissellement de 866 ha de terres situées dans une zone agricole et une zone résidentielle suburbaine partiellement en construction.

Quand les eaux de ruissellement pouvaient être stockées plus de douze heures, les matières en suspension ont été réduites de plus de 90%; les bactéries (coliformes totaux, coliformes et streptocoques d'origine fécale), de 75 à 90%; l'azote organique et les composés phosphorés totaux, de 25 à 50%.

Pour que le ruissellement soit mesurable il fallait au moins 5 mm de pluie. Les volumes d'eau de ruissellement engendrés par les pluies d'une et de deux heures susceptibles de survenir en 25 ans ont été évalués d'après le rapport entre le ruissellement et la pluie. À partir de ces données, on peut dire qu'il faudrait 40 000 à 47 000 m³ pour les eaux contenir de ruissellement d'une décennie. On a trouvé que la méthode la plus efficace consistait à maintenir le réservoir à un bas niveau, à fermer le robinet d'écoulement au moment du ruissellement et à laisser le bassin se remplir. Quand c'était possible, les eaux étaient conservées suffisamment longtemps pour en rendre la qualité acceptable. Quand le ruissellement dépassait la capacité de stockage, le trop-plein était évacué alors même qu'il était peu dépollué. Lorsque la qualité des eaux était jugée satisfaisante, le réservoir était vidé jusqu'à son niveau minimal. Par temps sec, on laissait l'eau s'écouler librement.

Parmi les facteurs qui décident du choix de la capacité de stockage, il faut compter la fréquence des ruissellements et la vitesse de vidange permise. Il a été établi que quatre jours séparent environ la moitié des trente précipitations prévues entre mai et septembre. Si l'on compte un jour pour le remplissage, un autre pour le stockage, la vidange du réservoir requiert deux jours.

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**Stormwater Runoff
Treatment by
Impoundment:
Barrhaven Pilot Study**

CONCLUSIONS

- 1) With over 12-hours retention time, it was possible, by gravity settling to remove: over 90 percent of suspended solids; 75 percent to 90 percent of bacteria; 20 percent to 50 percent of total phosphorus and organic nitrogen; and marginal quantities of nitrate nitrogen and BOD from the impounded stormwater. The process was generally most effective from July to September.
- 2) Total phosphorus and BOD in stormwater runoff appeared to be of minor significance. Throughout the study concentrations did not exceed 1 mg/L and 10 mg/L, respectively.
- 3) In the Barrhaven area 70 percent of rainfall events that produce runoff occur within six days of one another, and about 50 percent of the rainfall events happen within four days of one another. During a typical season (spring thaw to freeze-up) there are approximately 30 runoff events.
- 4) During heavy runoff, the pilot treatment system provided significant bacteriological loading reduction even when the runoff volume exceeded the treatment system volume.
- 5) As determined by laboratory jar tests, a dosage of 4 to 6 mg/L Al^{3+} or 6 to 8 mg/L Fe^{3+} was capable of producing an effluent with <10 mg/L suspended solids and <0.5 mg/L total phosphorus.
- 6) A pond storage volume of 40 000 to 47 000 m³ would dramatically reduce pollutant loadings from approximately 90 percent of the stormwater runoff now entering the Rideau River.
- 7) The following considerations should be applied in the design of the permanent or full-scale treatment system:
 - a) runoff storage for at least 12 hours of quiet settling should be provided,
 - b) discharge of the settled runoff should take no more than 48 hours,
 - c) the fill and empty treatment cycle should take a maximum of four days,
 - d) treated effluent discharge should be by a conduit to prevent recontamination at high discharge rates,
 - e) a shallow pond (0.3 - 0.5 m deep) should be provided within the system to prevent scouring of settled pollutants by dry weather flow.

- 8) Maximum flexibility of operation and the longest retention are provided when runoff is treated by filling the system and then discharging the treated effluent to maintain a shallow pond between runoffs.

RECOMMENDATIONS

The following recommendations are made, based on the results of this study:

- 1) A permanent gravity settling treatment system of 40 000 to 47 000 m³ should be constructed for the Barrhaven catchment area, to provide containment for 90 percent of the runoff expected.
- 2) The permanent treatment system should be capable of collecting, storing and discharging treated runoff within four days. The discharge rate should be such that the water quality of the Rideau River is not reduced.
- 3) The permanent treatment system should be as close as possible to the Rideau River to minimize submergence of the existing Barrhaven collector storm sewer. To reduce the effect of downstream contamination on the treated effluent, discharge should be through a conduit or lined channel.
- 4) The treatment system should be operated as a batch process.
- 5) Permanent flow measuring and sampling stations should be established to evaluate the permanent treatment system. Flow from the Madden Award Drain and the Barrhaven collector sewer, and treated effluent should be monitored.
- 6) The following additional data should be obtained from the Barrhaven treatment system (pilot or full-scale permanent):
 - a) performance of the system under heavy loading i.e. > five-year storms,
 - b) effect of the treated runoff on the Rideau River water quality,
 - c) the system's capability to provide treatment in compliance with effluent quality requirements.
- 7) A recording rain gauge should be installed in the Barrhaven residential area to provide rainfall intensity-duration data.
- 8) Further studies are required to evaluate the change in runoff pollutant loadings as the land surface is converted from agricultural to urban use.
- 9) Further data should be obtained on the runoff flows and pollutant loadings generated by the same rainfall on adjacent urban and agricultural lands.
- 10) Where more than one stormwater runoff treatment system discharges to the same watercourse, effluent discharge should be coordinated on a whole watershed basis, possibly through limits set on receiving water quality.

1 INTRODUCTION

The urbanization of agricultural and wooded lands has changed storm runoff drainage patterns and the characteristics of environmental pollutants carried by the runoff. These pollutants originate both from erosion of agricultural land surface and from urban or suburban areas where rainwater washes deposited contaminants into storm sewers. The use of storm drainage systems to collect and remove rainwater as quickly as possible has increased the slug loading of particulate, nutrient and bacteriological pollutants on the receiving watercourse.

Where the capacity of a receiving stream to assimilate and dissipate pollutants is limited, storm runoff can seriously restrict downstream recreational use of the river and stimulate undesired algae and aquatic weed growth. Several new large storm drainage systems, a result of rapid suburban development south of Ottawa, have threatened the water quality of the Rideau River.

A study was proposed to evaluate the feasibility of using impoundment in an open basin and gravity settling to remove pollutants from stormwater runoff, with the emphasis on runoff quality improvement. The hydrological effects of impoundment would be investigated only as necessary to derive loadings and evaluate different modes of treatment system operation.

Effectiveness would be determined in terms of concentration change and mass of pollutants removed. The treatment system would be operated both by filling and emptying the storage basin for each runoff event, and by maintaining the basin continuously full. If time permitted, the use of chemical flocculating agents would be evaluated.

This pilot-scale study would obtain data valuable in the design and operation of the full-scale facility.

1.1 Background

During the summer, when flow rates are low, the water quality of the Rideau River is especially sensitive to polluted discharges. Of particular concern is the bacteriological water quality, since swimming areas within the City of Ottawa are subjected to constant and heavy use. The desired maxima, as established by the Ontario Ministry of Health in the publication Water Quality Guidelines for Bathing Beaches, are 1 000 total coliform and 100 fecal coliform counts per 100 mL (geometric mean density of 10 samples monthly).

Storm drainage from the existing Barrhaven subdivision and an area proposed for immediate development, totalling about 99 ha, was to be discharged to the Rideau River about 8 km upstream of Mooney's Bay beach, a major swimming area within city limits. The Ontario Ministry of the Environment required that this runoff be treated. Consequently, the Regional Municipality of Ottawa-Carleton undertook to study storm-water runoff and a treatment method.

The Barrhaven collector storm sewer discharged into a long shallow ravine, suited to creating a reservoir by building a small dam. An award ditch system, which drained the balance of non-urbanized or agricultural land (approximately 800 ha), discharged to the ravine 15 m downstream. The impoundment was intended to trap and store runoff long enough to study the effectiveness of the settling process.

1.2 Objectives

This investigation was conducted to evaluate or determine:

- 1) the efficiency of temporary storage in removing suspended solids, five-day biochemical oxygen demand, nutrients and bacteria (total coliform, fecal coliform, fecal streptococcus) and other parameters;
- 2) techniques which would result in the most effective removal of pollutants;
- 3) the quantity and effectiveness of chemical flocculant application through both laboratory-scale and on-site testing; and
- 4) data useful in the design of the full-scale treatment system.

1.3 Scope of the Study

Work in 1975 was devoted mainly to construction of the pilot system, with as many sampling surveys as possible carried out. The system was operated as a constantly full basin with continuous overflow.

The following year the system was operated as a batch treatment basin, and was emptied between runoff events. After obtaining sufficient data on settling efficiency, the use of ferric chloride and alum as flocculating agents were evaluated both in laboratory jar tests and by addition to fresh runoff in the pilot treatment system.

Samples of stormwater runoff were analyzed for both chemical and bacteriological parameters. Frequency of sampling was adjusted to reflect the runoff flow rate. Samples were composited where the runoff was of long duration.

Dry-weather flow was also sampled, to evaluate the effect of the operation on water quality.

The parameters initially chosen for analysis were: suspended solids, total solids, pH, BOD₅, dissolved oxygen, chloride, ammonia nitrogen, nitrate nitrogen, organic (Kjeldahl) nitrogen, orthophosphorus, total phosphorus, total coliform bacteria, fecal coliform bacteria, fecal streptococcus bacteria and particle size. Those parameters showing little variation or demonstrated to be of little significance were discontinued. The parameters analyzed in 1976 were: suspended solids, BOD₅, nitrate and organic nitrogen, orthophosphorus and total phosphorus, and the three bacteria types. Volume and flow rate of runoff from both storm drains and rural drainage ditches would be measured whenever possible.

Data on rainfall intensity and duration were obtained from weather agencies and on-site rain gauges.

1.4 Description of the Study Area

The drainage area (Figure 1) is bounded by Jockvale Road on the west, by Merivale Road and Highway 16 on the east, by Fallowfield Road on the north and by Strandherd Road on the south. The total area drained is approximately 866 ha, and roughly 4.9 km long and 1.6 km wide.

In 1975 the urbanized area comprised 58.7 ha or about eight percent of the total catchment ⁽¹⁾. During storm sewer construction (May to October 1975) runoff flow entering the treatment system comprised overland flow (agricultural runoff) via the Madden Award Drain, flow originating in the suburban area under construction and from roadside ditches. This latter flow, although not runoff from residential suburbs, was conveyed by the storm sewer collector (see Figure 2).

In 1976, both the existing Barrhaven suburb and the area under construction made runoff contributions to the collector storm sewer (Figure 2). The area under construction increased the area contributing runoff by 40 ha or five percent.

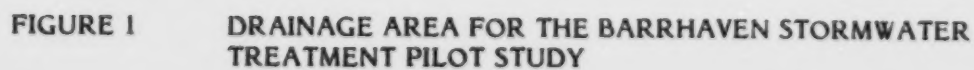
A breakdown of the land use in the study area was:

suburban use	- eight percent in 1975	- 13 percent in 1976
grass pasture	- 65 percent in 1975	- 60 percent in 1976
cultivated (grain)	- 22 percent	
woodlot	- five percent	

59 HA. (145 A.)

 40 HA. (100 A)

801 HA. (1978 A.)



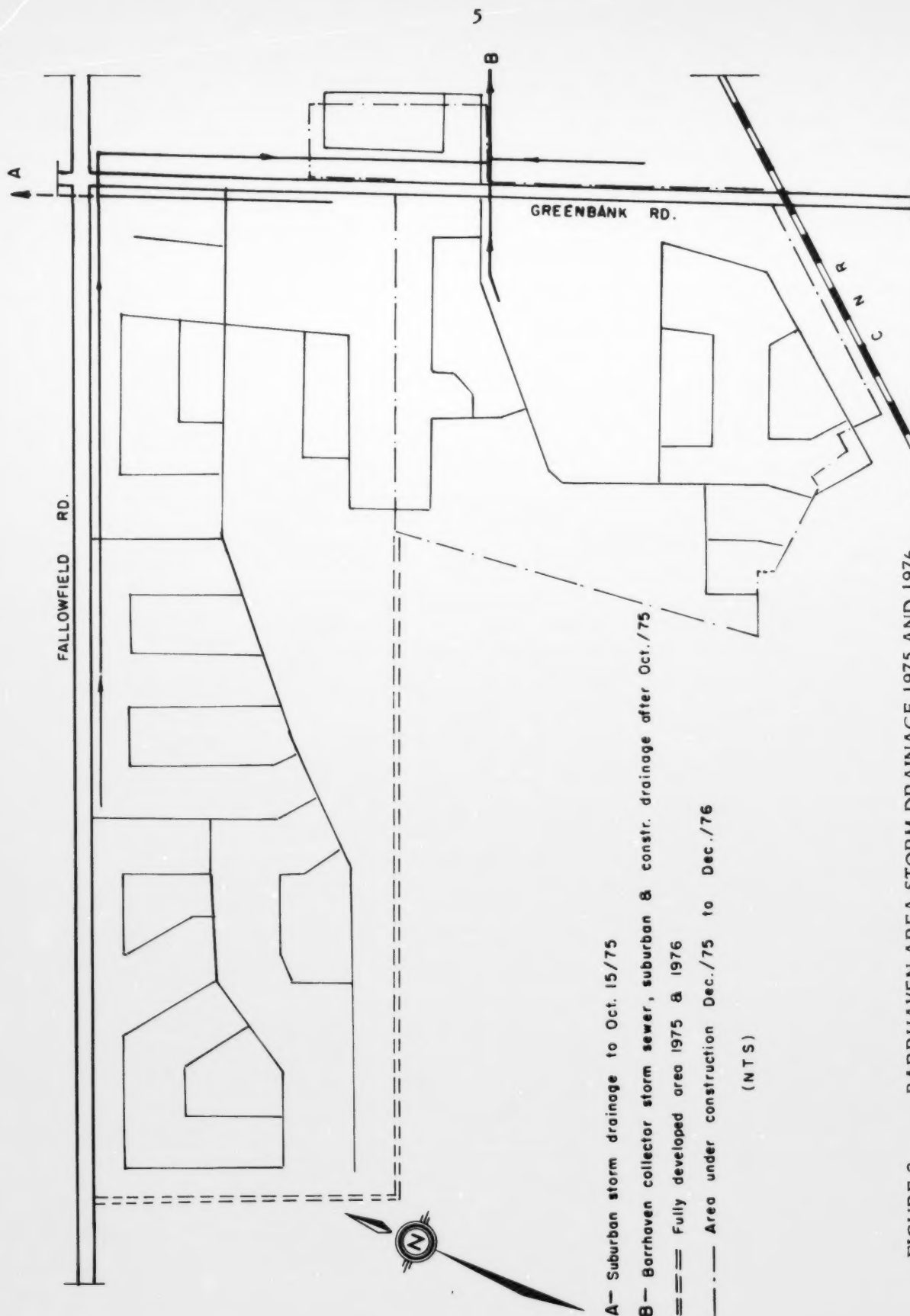


FIGURE 2 BARRHAVEN AREA STORM DRAINAGE 1975 AND 1976

The rural drainage is collected by the Madden Award Drain and by several field drainage ditches flowing west to east from Greenbank Road to Woodroffe Avenue (Figure 1). From Woodroffe Avenue, drainage is easterly via the Madden Award Drain and empties into a ravine between Woodroffe Avenue and Merivale Road. A smaller tributary, which collects runoff from the northeast corner of the area also enters the ravine here. The outfall of the 274-cm diameter Barrhaven collector storm sewer is 15 m upstream (Figure 3). From this point, the creek meanders some 1 100 m south through a wooded ravine and empties into the Rideau River.

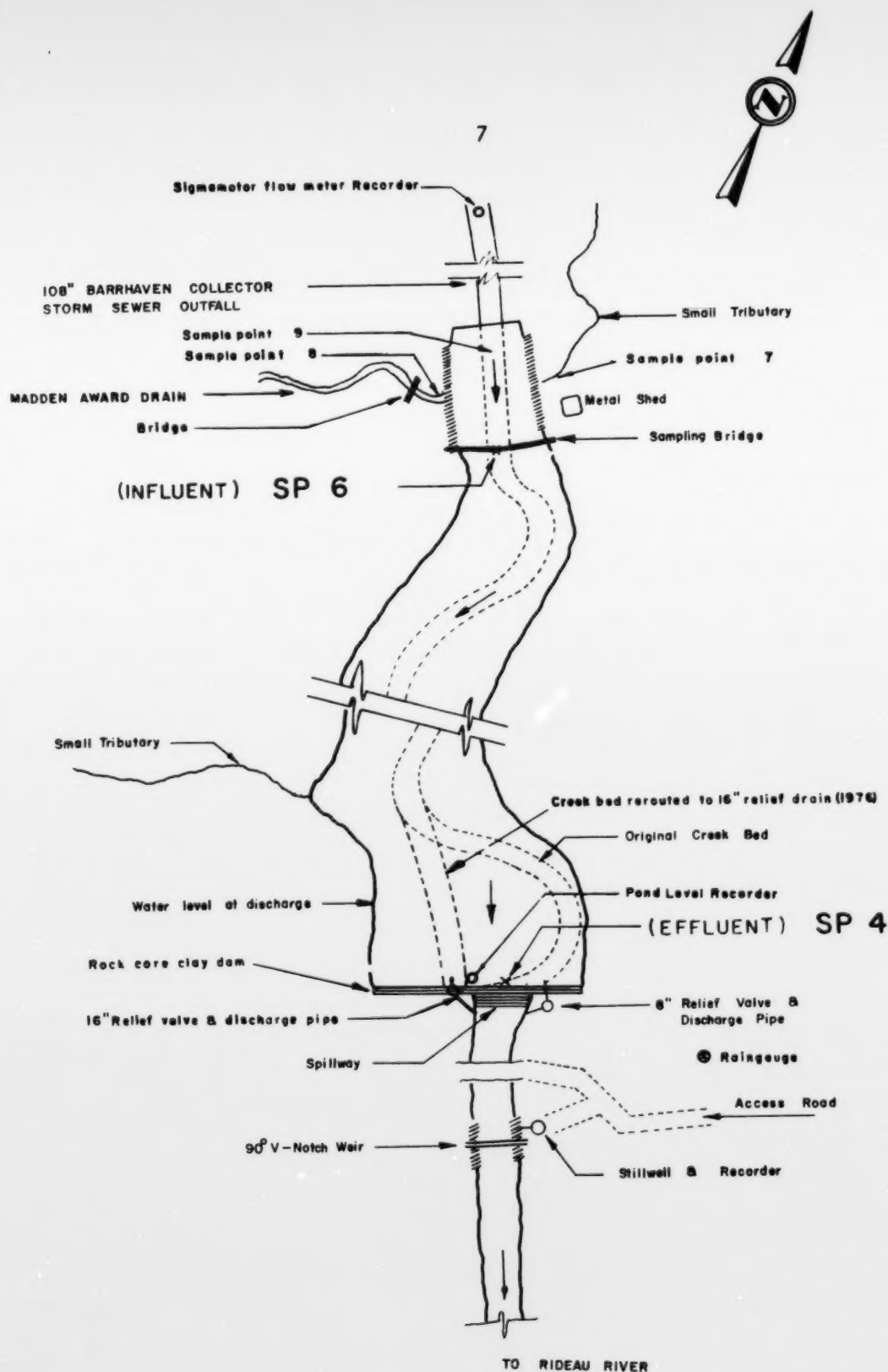


FIGURE 3 DETAIL OF BARRHAVEN PILOT STUDY RETENTION POND

2 THE PILOT TREATMENT SYSTEM

2.1 Selection of the Study Site

Because suburban development in the Barrhaven area was conditional on some treatment of stormwater runoff before it reached the Rideau River, the site for the study was limited to the ravine where the storm drainage was discharged. This limitation created several unattractive aspects for the study:

- 1) the study site was over 30 km from laboratory facilities;
- 2) the treatment system received runoff from both overland flow (agricultural runoff) and suburban runoff;
- 3) the small elevation difference between treatment pond inlet and outlet made inlet flow measurement difficult when the pond was full.

2.2 Construction of the Dam and Retention System

In November-December 1974, a granular core, clay-lined dam was constructed 500 m below the trunk storm sewer outfall (Figure 4). The reservoir created had a storage volume of 500 m^3 , an average depth of one meter and a surface area of one hectare. Treated effluent was discharged through either a 5.5-m wide spillway on the crest of the dam or a 20-cm pipe and valve, which permitted the storage basin to be drained to confine dry weather flow to the original creek channel. Three to four days, rather than the planned 24 hours, were required to drain the pond.

In October 1975, the dam was raised 0.52 m to its final elevation of 84.5 m creating a pond depth of 1.5 to 2 m, and a surface area of 1.3 ha. A deeper pond was desired to:

- a) increase hydraulic retention time;
- b) reduce linear flow velocity to promote settling and minimize scouring;
- c) provide more uniform distribution of flow over a wider cross section of the pond to reduce the effect of channeling.

The storage volume was increased from $5\,000 \text{ m}^3$ to $10\,500 \text{ m}^3$, more than doubling the retention time.

Heavy runoff in March 1976 washed out a large section of the dam. The structure was rebuilt as before, with one addition; a 41-cm diameter relief drain with gate valve was placed on the west side of the spillway, permitting the reservoir to be drained in 24 hours. The elevation of the rebuilt spillway was 84.6 m.

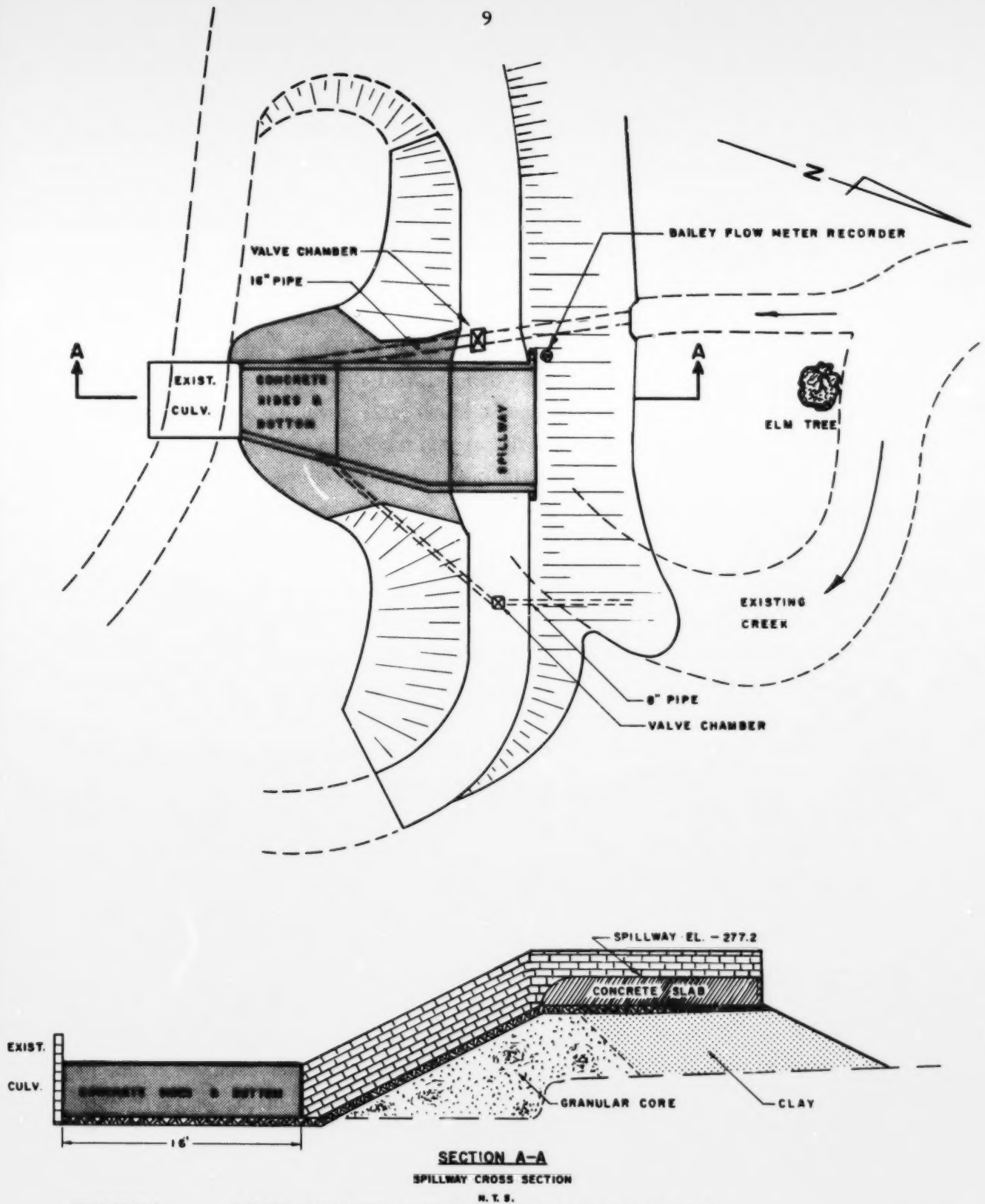


FIGURE 4

BARRHAVEN PILOT STUDY DAM CONSTRUCTION

2.3 Flow Measuring Systems

Sharp-edged weirs or flumes were used whenever possible with automatic water level recording devices of the bubbler or float types. (See Table 1.) Rating curves are provided in Appendix I.

2.3.1 Agricultural Runoff Measurement. Attempts to measure the agricultural or overland flow hydrograph in the Madden Award Drain were unsuccessful. In 1975, the settling basin discharge hydrograph (from Sample Point 4) was integrated to obtain the total volume of runoff. It was then assumed that the effluent volume and influent volume were equal. Loadings were developed as discussed in following sections.

In 1976, the overland (agricultural) runoff volume was calculated by subtracting the storm sewer flow (Sample Point 10) from the total pond effluent flow. Since rainfall distribution often was non-uniform, overland flow could be generated with no storm sewer flow or vice versa. (Sample Points 4, 6 and 10 are shown on Figure 1.)

2.4 Water Quality Monitoring

2.4.1 Sample Points. The runoff at Sample Point 10 was sampled only in 1976, when the flow was characteristic of residential suburban runoff, with some contribution from an area undergoing construction (Figure 2).

Sample Point 6 was 30 m downstream of the storm sewer outfall and about 15 m downstream of the confluence of the Madden Award Drain. A plank bridge was constructed to permit sampling from midstream of the old creek bed, which was about 1.5 m deep and 3 m wide.

In 1975, flow at Sample Point 6 was from agricultural land. But in 1976 the storm sewer contribution was residential runoff including an area undergoing construction. Each rainstorm did not always generate both overland and storm sewer flows. Depending on the storm pattern and duration it was possible to obtain only suburban runoff, only agricultural runoff, or a combination. An assessment of area storm patterns was made for each rainfall, using the total accumulated rainfall at four rain gauge locations (Figure 1).

Flow that had passed through the treatment pond was sampled at Point 4 (Figure 3) at the spillway, or directly behind it if there were no discharge. Automatic sampling devices were placed on the upstream side.

2.4.2 Sampling Technique. Two grab samples, one for chemical and one for bacteriological analyses, were taken in all cases. Analyses for BOD, orthophosphorus,

TABLE 1 SUMMARY OF FLOW MEASURING SYSTEMS

Source of Flow	Type of Flow Control Section	Location	Flow Range and Estimated Error (%)	Level Sensing by	Rating Curve* or Calibration by
Residential suburban storm sewer	Palmer-Bowlus flume in 183 cm sewer	SP 10	0.014 to 4.67 m ³ /s 0.014 - 0.85 m ³ /s ± 7% 0.85 - 4.53 m ³ /s ± 5%	bubbler	calculated
Infiltration ** residential suburban storm sewer	274-cm RCP storm sewer	300 m upstream of SP 6	0 to 0.8 m ³ /s ± 10%	bubbler	velocity meter and cross section area
Agricultural runoff (overland flow)					
Madden Award Drain	-	-	see Section 2.3.1	-	-
Treated storm water	90° V-notch weir	30 m downstream of dam	0.56 x 10 ⁻³ to 0.56 m ³ /s ± 5%	bubbler	calculated
	spillway on dam (rectangular channel)	SP 4	0 to 20 m ³ /s ± 8% 10 m ³ /s plus ± 15%	float	90° V-notch weir 0-0.56 m ³ /s, and calc. by Francis' formula (2)

* Rating curves and error estimations - Appendix I

** Infiltration was insignificant with respect to pollutant loadings.

organic nitrogen and bacteria were usually completed within four to six hours of sampling. Other samples were preserved according to Standard Methods⁽³⁾, and refrigerated.

2.4.3 General Considerations. Considerable difficulty was encountered at first in reaching Sampling Point 6 before the hydraulic and pollutant peaks had entered the treatment system. This was mainly because of the lack of advance notice of rainfall, and because the study site was 35 km from the laboratory.

An approximation of the site weather was obtained from the Ottawa airport weather office. If conditions were appropriate the field crew team leader visited the site to determine if a sampling program was warranted. Usually a rainfall accumulation of over 7 mm was required for significant runoff, but this depended on antecedent conditions. It was the responsibility of the team leader to initiate the survey, call in required personnel, and manage and direct all activities, including transportation of samples and starting the analytical work.

In 1976 residential suburban runoff was intercepted at Sample Point 10. Because of the higher degree of imperviousness (25 percent - 30 percent) and the short time of travel of runoff through the storm sewer system, runoff often reached the sampling point 15 to 20 minutes after the start of rainfall, so it was necessary to have personnel at the site before rain began.

2.4.4 Dry-Weather Sampling. In 1975 the storage pond was operated as a continuous flow system, with the pond filled and overflowing the spillway. There were occasions when the reservoir was either being filled or drawn down when dry weather sampling took place. Because of the wide variation in retention times under these different conditions, no attempt was made to collect samples one retention time apart. Flows seldom varied much diurnally from the average dry-weather flow. Hydraulic retention time usually ranged from one to six days, sufficient to permit maximum settling.

In 1976, since the pond was usually kept empty, dry-weather flow followed the original creek bed and passed directly through the treatment system. Here, the time of travel throughout the system was still five to eight hours so in-phase sampling (i.e., sampling the influent and effluent one retention time apart) required two daily trips to the site. Because of the increased cost, however, this was not done. Sampling times were instead varied from morning to early afternoon to obtain results which would accurately represent usual dry-weather flow conditions.

2.4.5 Wet-Weather Surveys. Efforts concentrated on sampling the influent first flush, and the treated effluent one retention time later. Influent pollutants usually were indicated by a more turbid flow. Sampling was begun sufficiently in advance of the turbidity to define the first flush peak.

The gradual slope of the ravine created sampling problems when the reservoir was filled. The fall between Sample Point 6 and the base of the dam was only 1.3 m. As the water level rose, the outfall of the storm sewer was submerged and water backed up over 90 m into the Madden Award Ditch. As a result, some suspended material may have settled out before being sampled, especially when flow velocities were low. Heavier storm runoff usually produced high enough flow velocities to maintain all but the heaviest particles in suspension. At Sample Point 10 high-flow velocities (i.e., sufficient for scour) usually existed during runoff.

The settlement problem was reduced when operating with the reservoir empty. The first flush usually reached Sample Point 6 under free-flow conditions.

Sampling treated effluent was more difficult. Again, the object was to collect such samples as would define the effluent pollutant peaks; however, estimation of the retention time was difficult because of the changing pond volume. A dye tracer was added to the reservoir to attempt to measure retention times, but the high dilution and the masking effect of suspended solids rendered this ineffective. The hydraulic peak was sometimes used as an indicator of the position of pollutants, but the hydraulic and pollutant peaks did not coincide. The only sure procedure was to begin sampling far in advance of the turbidity front.

A uniform procedure for collecting samples was maintained. At Sample Points 4 and 6, baseline values of parameters were established by sampling at intervals of one to three hours before the turbidity front. Just before the turbidity reached the sampling point, the time between samples was reduced to 30 minutes and then to 15 minutes for the estimated duration of the peak. Three to four hours after the front had passed, the interval was increased to two or three hours. Sampling was continued either until baseline flow was re-established, or until the effluent was clear. At Points 6 and 4, sampling periods were rarely less than 12 hours, and sometimes as long as several days.

At Sample Point 10 in the storm sewer, (and often at Point 6) the first flush pollutant peak and the hydraulic peak usually coincided. Flow measuring instrumentation was used as an indicator of sampling frequency for low-intensity rainfalls. Again, a

baseline was established by sampling before runoff reached Point 10. As flow increased, samples were taken at shorter intervals, sometimes as little as 10 to 15 minutes. The runoff resulting from high-intensity rainfalls usually gave high peaks of relatively short duration, which required short intervals (five minutes) between samples be used. Sampling continued until either the runoff became clear or flow returned to the baseline value.

Because runoff flow rates varied from storm to storm, sampling could not be fixed. Field personnel relied on judgment and experience to obtain samples representative of actual pollutant concentrations.

Two samples were taken, a 230 mL bacteriological sample, and a 4.5 L sample for chemical and physical analyses⁽³⁾. Automatic samplers were often used. These were of the evacuated bottle type (North Hants Engineering Co., types 3B and 4B) capable of taking either 12 or 24 discrete samples half-hourly, hourly or bihourly. However, reliable operation was a problem, especially in heavy rain. Another drawback of this type of sampler was that individual sample quantities were too small for both chemical and bacteriological analyses. Cross-contamination of bacteriological samples was possible since the intake line was not purged between samples. For these reasons automatic sampling equipment was used as a last resort.

Any full-scale survey required three or four people in the field for sampling and sample retrieval, and two or three more to carry out bacteriological analyses and BOD₅ analyses. Analyses for bacteria, BOD₅, nitrate and orthophosphorus were started as quickly as possible after sampling.

During the 1975 season, over 1 600 bacteriological and chemical samples were collected with over 10 700 individual analyses run. In 1976 over 900 samples were taken and more than 4 000 analyses run.

3 SURVEY PROGRAM RESULTS AND DISCUSSION

3.1 Dry-Weather Performance

Dry-weather flow and water quality indicate the significance of the catchment area as a pollutant contributor to the receiving water, and its importance relative to other catchment areas in the watershed.

A highly polluted dry-weather flow would suggest that:

- a) a point source or sources may exist which could be eliminated (e.g., raw sewage discharges to storm sewers, manure or silo drainage and industrial waste discharges), and
- b) non-point sources exist which may require larger or more sophisticated treatment systems than ponding to provide the desired degree of treatment.

Dry-weather water quality parameters are shown in Table 2. In 1975, samples were taken at the inlet to the reservoir; for 1976 the additional results from storm sewer flow at the flume are given. In general, there is only a small variation in most parameters between the two sampling periods.

The low values indicate that most of the pollution was from non-point sources. No flow existed in the Madden Award Drain between rainfalls, but in the storm sewer, infiltration and the dewatering of excavations by contractors created a continuous flow.

Effluent from the pond was also sampled during dry-weather flow. A higher concentration of suspended solids, total phosphorus and bacteria was discharged when the pond was empty.

Table 3 shows the effluent parameters for dry-weather flow with the pond empty and not empty (i.e., dry-weather flow was either contained in the pond or overflowing the spillway).

A significant reduction of several pollutants resulted from keeping some water in the pond. The greatest reduction (compared with storm sewer flow) was in suspended solids, with significant removal of total and orthophosphorus. When the pond was drained, on the other hand, all parameters showed increased concentrations, from scouring caused by the higher flow velocity.

These observations suggested that the highest quality dry-weather flow for a permanent treatment system would be obtained with some water stored in the retention basin. Under dry-weather flow conditions, the retention basin would act as a polishing lagoon.

TABLE 2 DRY-WEATHER FLOW WATER QUALITY

Parameter	1975	1976	
	Pond Influent	Pond Influent	Storm Sewer Flow at SP 10
Flow m ³ /s	0.03	0.02	0.014
Suspended solids mg/L	4.6	5.5	10.2
Total solids mg/L	403	-	935
pH	8.0	8.0	7.8
BOD ₅ mg/L	3	<2	1
Dissolved oxygen mg/L	7.9	-	8.1
Nitrate (as N) mg/L	0.76	0.87	0.48
Organic nitrogen (as N) mg/L	0.24	0.31	0.30
Ammonia nitrogen (as N) mg/L	< 0.1	-	< 0.1
Total phosphorus (as P) mg/L	0.046	0.062	0.044
Orthophosphorus (as P) mg/L	0.008	-	0.008
Total coliform counts/100 mL	680	1300	332
Fecal coliform counts/100 mL	30	60	16
Fecal streptococcus counts/100 mL	80	170	28

It was observed that a permanently flooded pond was attractive to wildlife. Several pairs of wild ducks used the area for nesting, and the pond was the centre of activity for other small animals such as muskrat and raccoon. Both ecologically and aesthetically, the presence of such a pond in a wooded ravine is attractive. Should further development take place around the ravine, the pond would become a pleasant recreation area and increase the value of abutting property.

3.2 Rainfall in the Barrhaven Area

3.2.1 Rainfall During the Study Period. Rainfall data for April 1975 to December 1976 were gathered from several sources. Data from the meteorological office at Ottawa International Airport (OIA) about 3 to 8 km east of the study area, and from Agriculture Canada's Central Experimental Farm weather station north of the study area, consisted of complete monthly weather bulletins with rainfall intensity-duration records ⁽⁴⁾.

TABLE 3 COMPARISON OF PARAMETERS FOR POND EFFLUENT AND STORM SEWER FLOW

Parameter	Effluent Pond Not Empty	Effluent Pond Empty	Storm Sewer Flow at SP 10
Suspended solids mg/L	4.5	25.9	12.8
BOD ₅ mg/L	2	< 1	< 1
Nitrate (as N) mg/L	0.87	0.71	0.57
Organic nitrogen (as N) mg/L	0.34	0.28	0.17
Total phosphorus (as P) mg/L	0.059	0.082	0.051
Orthophosphorus (as P) mg/L	0.006	0.010	0.008
Total coliform counts/100 mL	370	800	380
Fecal coliform counts/100 mL	35	35	20
Fecal streptococcus counts/100 mL	100	132	18

A comparison of the average monthly rainfall for both weather stations indicated that data from both could be used. (See Table II.2).

Regional personnel installed rain gauges at various locations throughout the drainage area (Figure 1). In 1975, rain gauges No. 1 and No. 4 were in use; in 1976 gauges were added at No. 2 and No. 3 locations. These gauges measured only the total accumulated rainfall. Table 4 presents the monthly rainfall for the study period as measured by the rain gauges. The total monthly rainfall is also shown as a percentage of the past average rainfall for comparison.

In 1975, rainfall approached or exceeded the average monthly rainfall only in September and October. August and November were dry months. In 1976, June, July and October were dry months with only 35 percent of the past monthly average. August and September had more rain, with an average of 89 percent, still significantly below the past monthly average. The number of rainfall events exceeding 5 mm was 20 in 1976, and 37 in 1975. For most storm events, rainfall in excess of 5 mm was required to produce measurable runoff.

A total of 22 storm runoff surveys were initiated, nine in 1975 and 13 in 1976. Seven did not produce sufficient runoff to warrant complete surveys.

TABLE 4 COMPARISON OF STUDY AREA MONTHLY RAINFALL WITH HISTORICAL
AVERAGE MONTHLY RAINFALL

Study Period	Rain gauge No. 1		Rain gauge No. 2		Rain gauge No. 3		Rain gauge No. 4		Number of Rain- fall Events per Month	Number of Events with Rainfall Exceeding 5 mm
	Rain- fall (mm)	% of Past Avg. Rain- fall	Rain- fall (mm)	% of Past Avg. Rain- fall	Rain- fall (mm)	% of Past Avg. Rain- fall	Rain- fall (mm)	% of Past Avg. Rain- fall		
1975										
Apr.	0.0		NR*		NR		NR		5	1
May	6.4	9	NR		NR		NR		4	4
June	54.7	74	NR		NR		NR		12	4
July	75.3	87	NR		NR		NR		15	6
Aug.	10.4	13	NR		NR		11.4	14	14	2
Sep.	117.7	154	NR		NR		68.7	90	22	8
Oct.	65.2	102	NR		NR		50.8	79	15	6
Nov.	28.8	52	NR		NR		18.0	32	4	6
1976										
June	29.9	40	32.0	43	34.6	47	41.7	56	15	3
July	16.8	19	16.1	79	17.9	21	15.0	17	9	2
Aug.	55.1	70	78.3	99	55.9	71	61.7	78	8	3
Sep.	82.5	108	63.9	84	70.7	92	83.3	109	13	7
Oct.	30.4	48	25.4	40	22.8	36	20.3	32	8	4
Nov.									6	1

* NR - Rain gauges not installed during these months.

3.2.2 Runoff to Rainfall Ratio. Where runoff flows were not measured directly, total runoff volumes were estimated from a runoff to rainfall ratio developed from data on the suburban residential catchment (Appendix II).

Data were taken from 18 runoff events in 1976 (Appendix II). Two cases were considered: no antecedent rainfall for four days and all events regardless of antecedent conditions. For the former, the ratio of runoff to rainfall was 0.133 and for the latter it was 0.138 (estimated error of 10 percent). The slight difference indicated that, for the events observed, antecedent conditions had little effect.

The analysis of runoff and rainfall also showed (Figure II.1, Appendix II) that runoff began only after some 6 000 m³ of rain had fallen. This was the equivalent of 5 mm of rain. Field observations indicated that 5 to 7 mm of rain were required to produce runoff, a good agreement with the calculated result.

The ratio is equivalent to the Rational formula runoff coefficient and can be compared with runoff coefficients for various types of tributary surface (5):

Residential (suburban)	0.25 to 0.40
Parks	0.10 to 0.25
Lawns in heavy soil (flat to 2-7 percent slope)	0.13 to 0.22

The observed ratio was less than that expected for a suburban residential area because almost half the contributing area was under construction during the study. It corresponded to the upper range of park or grassland.

The ratio was used to estimate the volume of residential suburban runoff, except in the case of the rainfall of September 12/75.

Lack of flow data required that the overland runoff volume be estimated, even though it was realized that the ratio was derived from residential flows. This probably resulted in a higher volume than actually obtained, but made it possible to calculate reasonable pollutant loading reduction by the treatment system.

3.3 Monitoring of Stormwater Runoff

The runoff monitored may be characterized according to the nature and origin of the flow as it entered the treatment system: storm sewer flow (residential suburban) and overland flow (agricultural drainage).

Until October 15, 1975 all flow entering the pilot treatment system was agricultural drainage. Any contribution made by the storm sewer system carried no residential suburban drainage. After this date the residential storm drain system was

connected to the collector sewer which discharged into the treatment system. Runoff samples at Point 10 (Figure 1) were characteristic of suburban residential runoff, although about 40.5 ha of the 99 ha catchment were under construction.

3.3.1 Pollutant Concentrations in Stormwater Runoff. The changes in concentration of various parameters during a runoff event are illustrated by the sample results of two runoff flows (Figures 5 to 25).

On November 10, 1975, a very heavy rainfall (18 mm in six hours) generated overland runoff from both the Madden drain and the small creek east of the storm sewer outfall. No contribution entered the treatment system from the storm sewer outfall. During this event the heaviest rainfall was 4.6 mm in 30 minutes. The intensity of the rainfall and the fact that the soil surface was still wet from rain on November 8 resulted in almost immediate runoff. The time of travel of the suspended solids through the system was 9 to 10 hours. After about nine hours, effective treatment had ceased as indicated by the suspended solids discharge concentration (Figure 7). The influent and effluent concentrations of suspended solids became the same, indicating that one pond volume ($10\,400\text{ m}^3$) had been displaced, with the remainder of the runoff receiving little treatment.

The effluent flow peak was discharged from the system before the pollutants reached the discharge point (compare the peak locations, Figures 6 and 7). This peak consisted of stored rather than runoff water and so contained few pollutants. The discharge of this relatively pure water is a desirable consequence of operating the impoundment in the flow-through mode.

The displacement of a second pond volume took another 24 hours, at which time both influent and effluent suspended solids concentrations decreased to about 10 mg/L. (Figure 5 shows the rainfall pattern.) Since OIA weather office shut down its tipping bucket rain gauges on October 31, rainfall intensity duration data were gathered by field personnel using total accumulation rain gauges. Data were inadequate to plot an hyetograph.

Suburban runoff was sampled at Point 10 (Figure 1). A moderate rain on September 18, 1976, resulted in the runoff concentration curves shown in Figures 17 to 25. This rainfall lasted five hours with a total accumulation of 17 mm. The most intense rainfall was 10.1 mm for 30 minutes. The treated runoff was observed on September 21.

In general, the pollutant maxima in both suburban and overland runoff passed by a given sampling point in two groups. The first contained all the chemical and physical

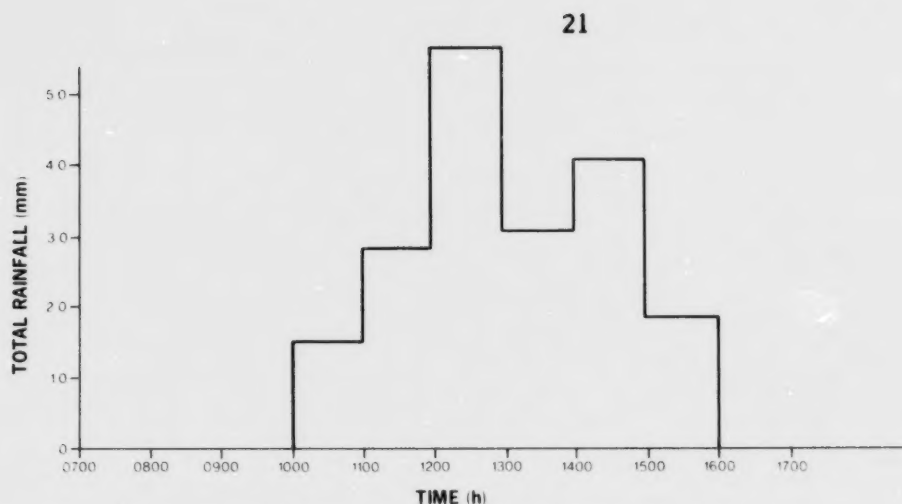


FIGURE 5 RAINFALL PATTERN, NOV. 10, 1975

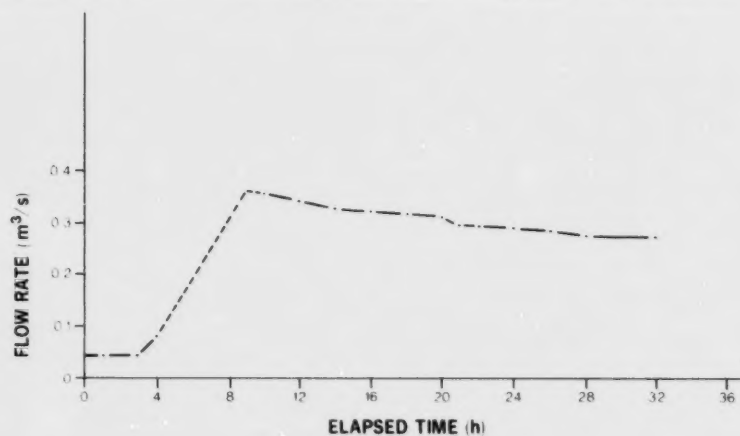


FIGURE 6 EFFLUENT FLOW HYDROGRAPH, NOV. 10, 1975

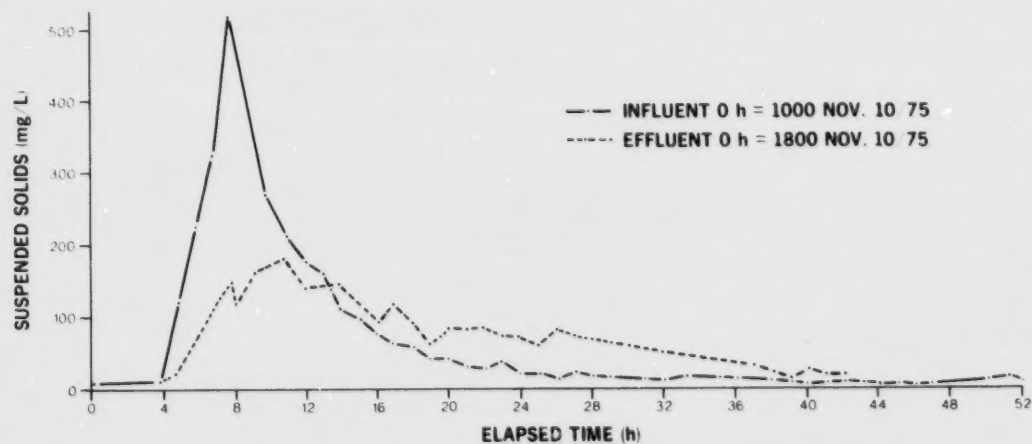


FIGURE 7 SUSPENDED SOLIDS, NOV. 10, 1975

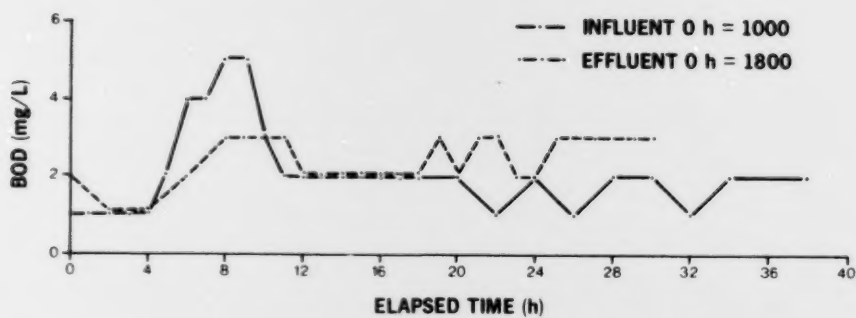


FIGURE 8 BOD, NOV. 10, 1975

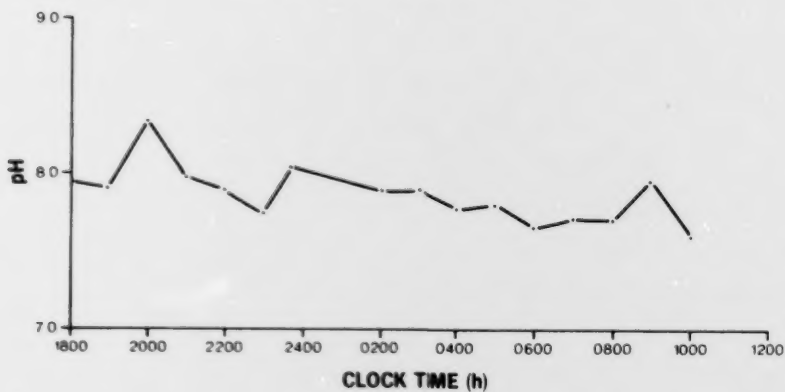


FIGURE 9 pH, NOV. 10, 1975

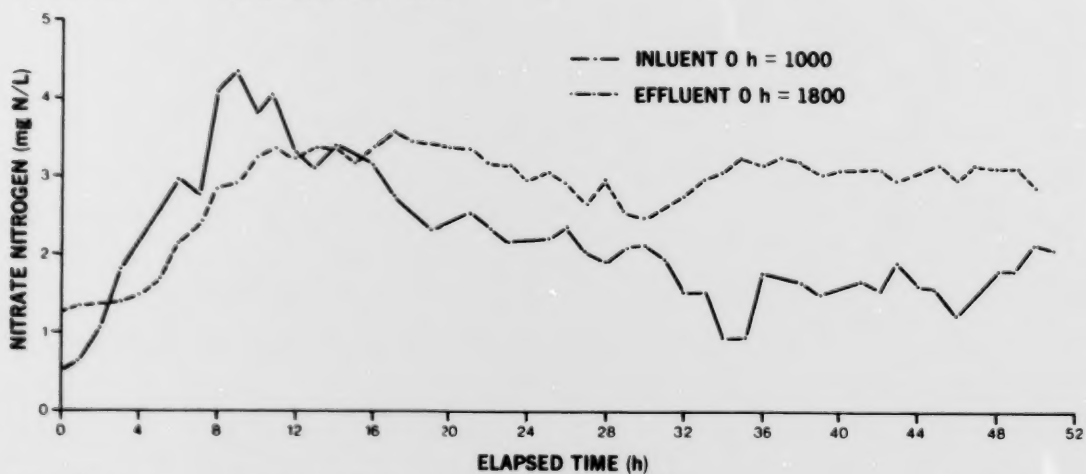


FIGURE 10 NITRATE NITROGEN, NOV. 10, 1975

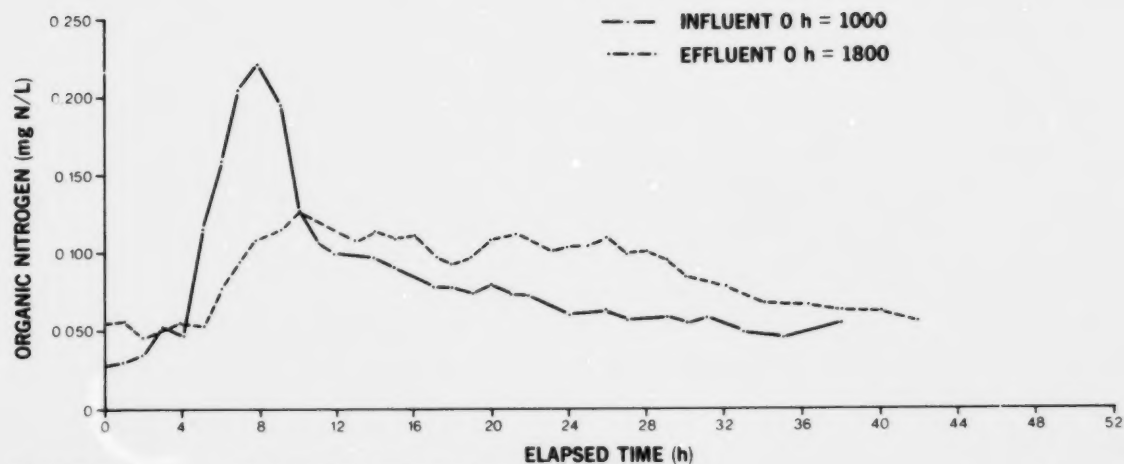


FIGURE 11 ORGANIC NITROGEN, NOV. 10, 1975

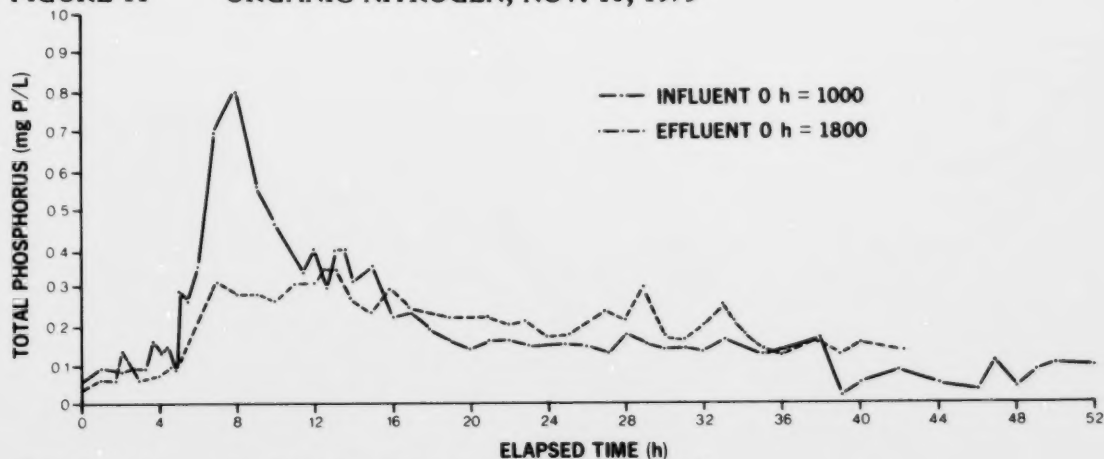


FIGURE 12 TOTAL PHOSPHORUS, NOV. 10, 1975

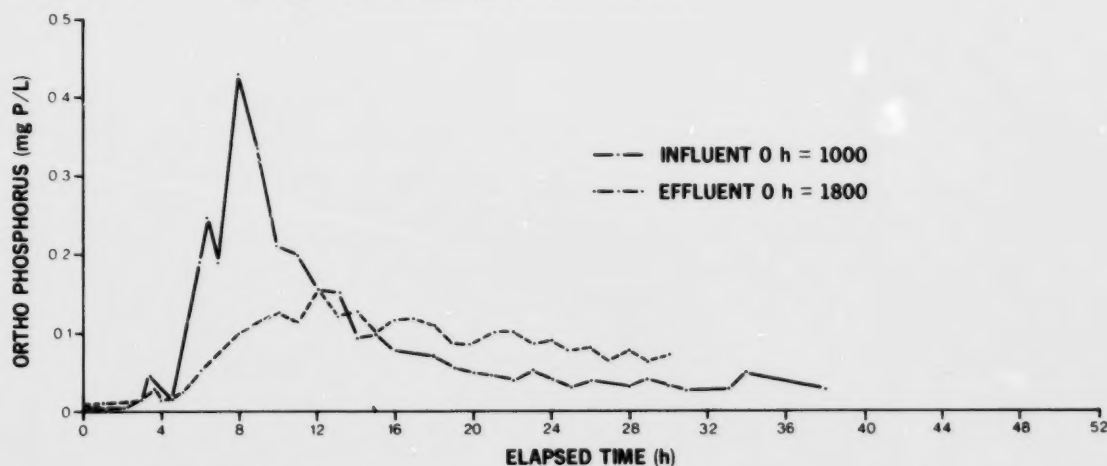


FIGURE 13 ORTHOPHOSPHORUS, NOV. 10, 1975

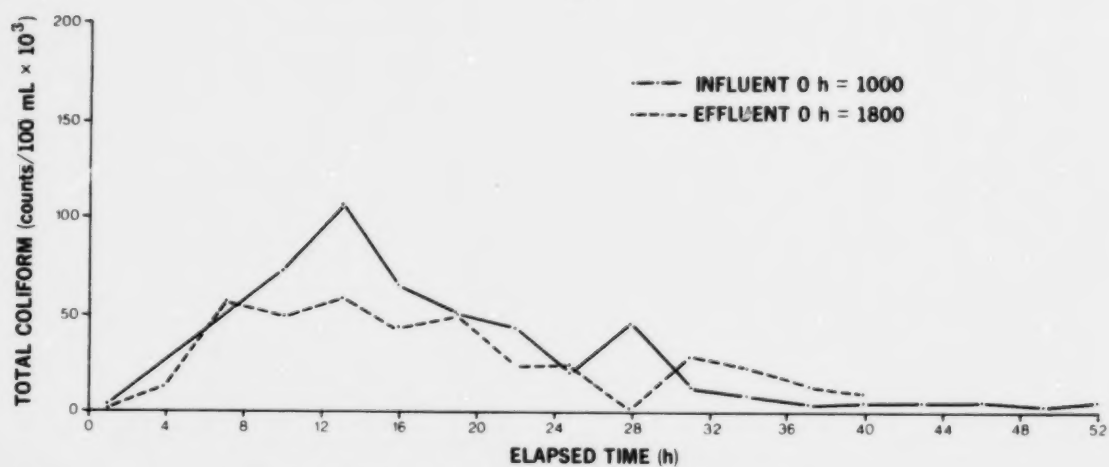


FIGURE 14 TOTAL COLIFORM COUNTS, NOV. 10, 1975

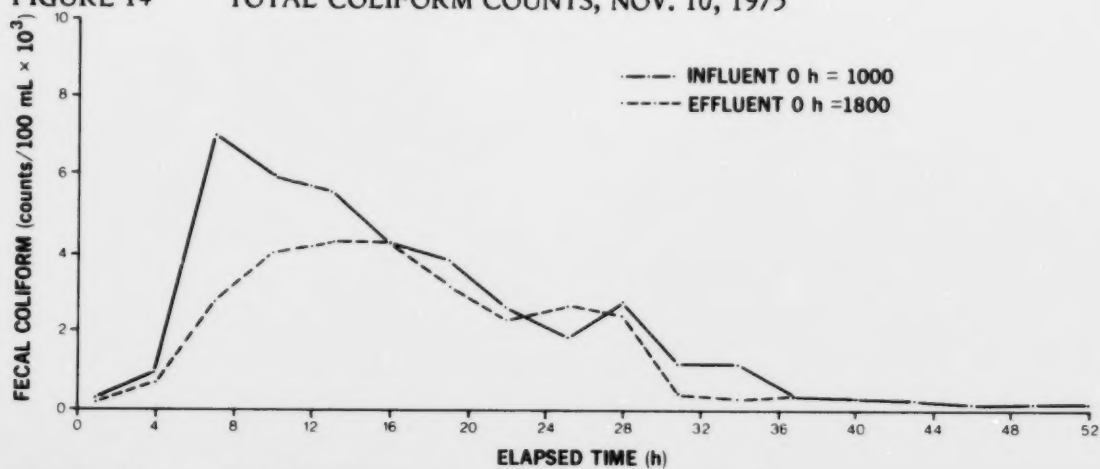


FIGURE 15 FECAL COLIFORM COUNTS, NOV. 10, 1975

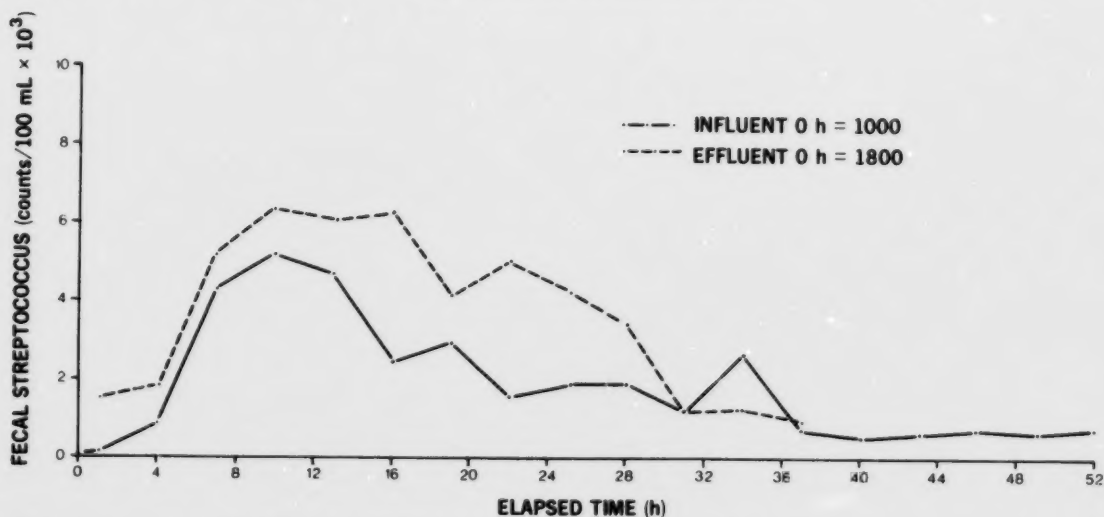


FIGURE 16 FECAL STREPTOCOCCUS COUNTS, NOV. 10, 1975

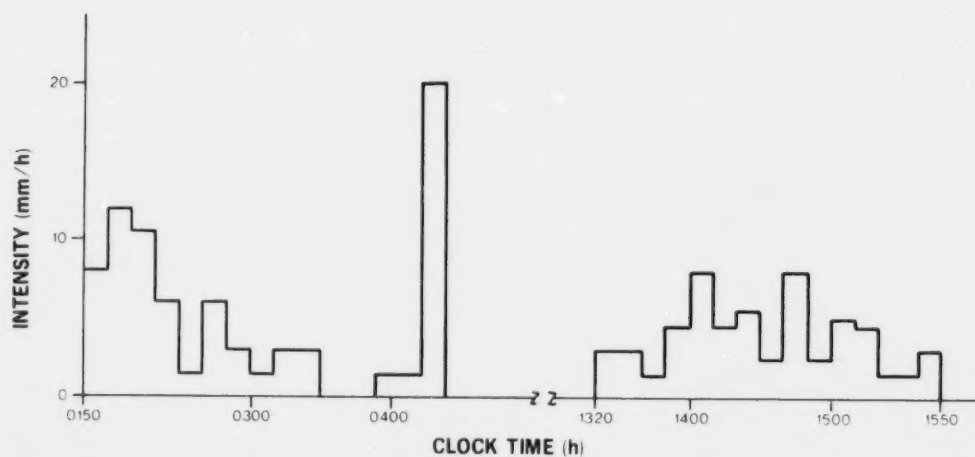


FIGURE 17 RAINFALL HYETOGRAPH, SEPT. 18, 1976

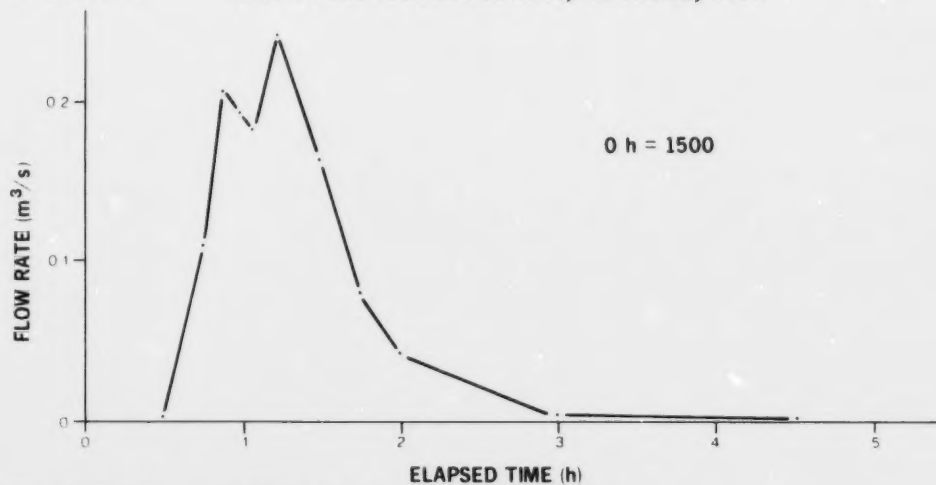


FIGURE 18 HYDROGRAPH, SEPT. 18, 1976

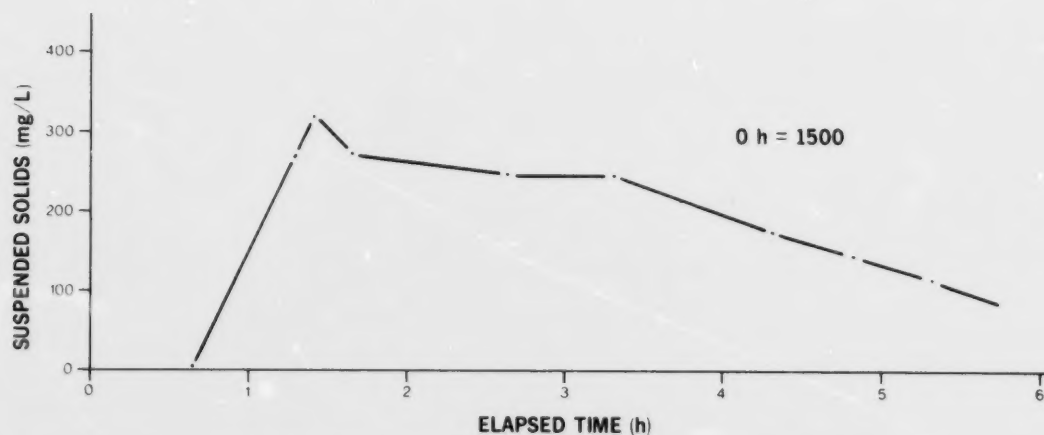


FIGURE 19 SUSPENDED SOLIDS, SEPT. 18, 1976

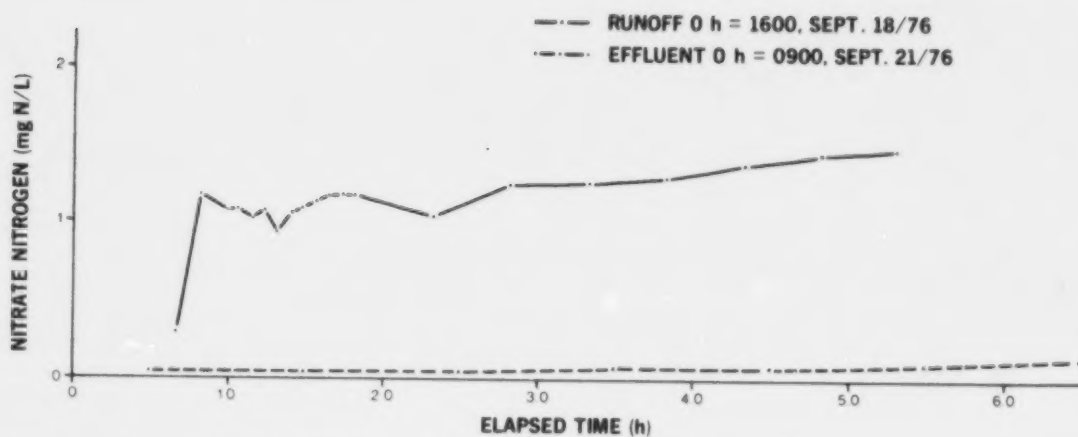


FIGURE 20 NITRATE NITROGEN, SEPT. 18, 1976

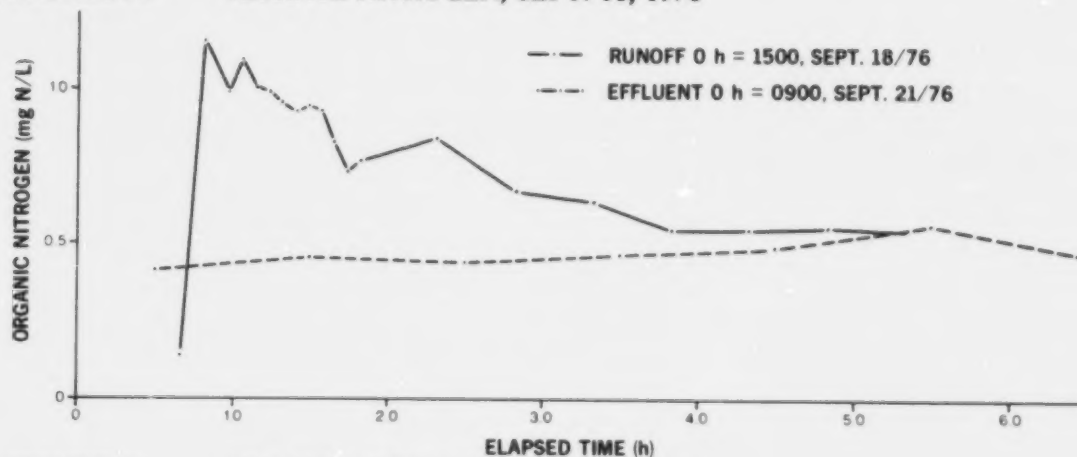


FIGURE 21 ORGANIC NITROGEN, SEPT. 18, 1976

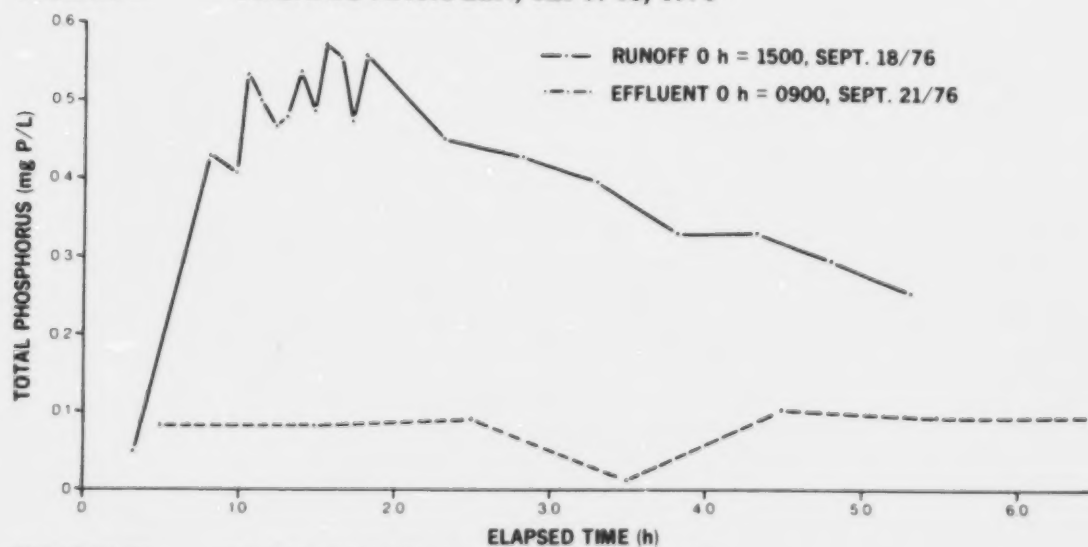


FIGURE 22 TOTAL PHOSPHORUS, SEPT. 18, 1976

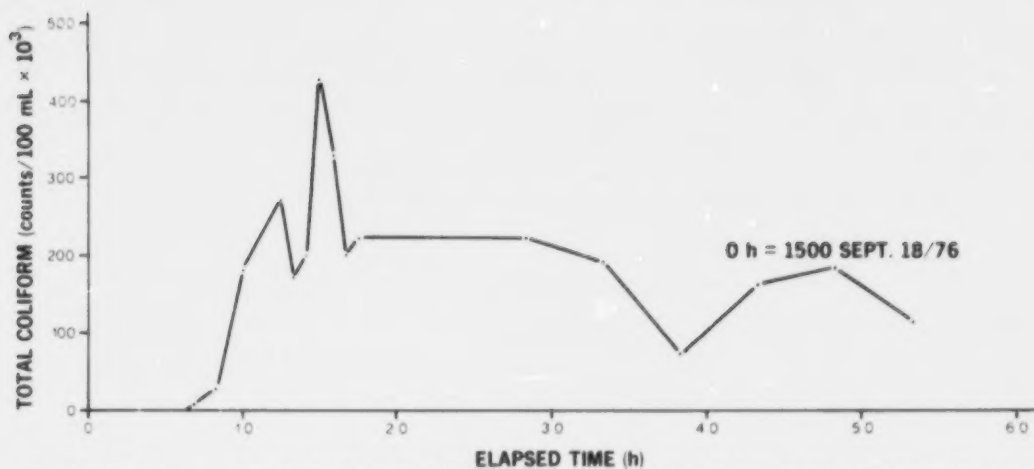


FIGURE 23 TOTAL COLIFORM COUNTS, SUBURBAN RUNOFF, SEPT. 18, 1976

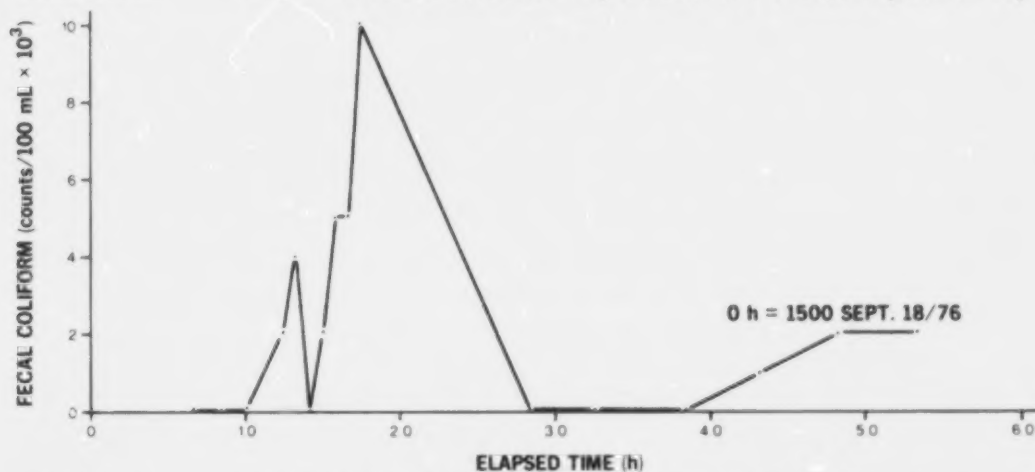


FIGURE 24 FECAL COLIFORM COUNTS, SUBURBAN RUNOFF, SEPT. 18, 1976

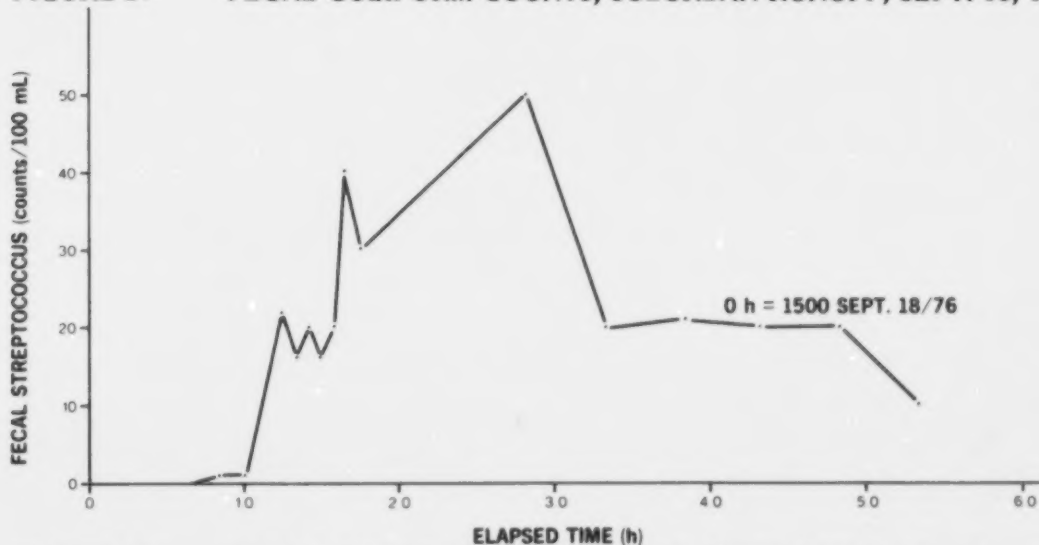


FIGURE 25 FECAL STREPTOCOCCUS COUNTS, SUBURBAN RUNOFF, SEPT. 18, 1976

parameters, while the second contained the bacteriological parameters. The time between the groups was about 15 minutes for storm sewer flow and usually over an hour for overland runoff. The time delay depended on the intensity and duration of rainfall and the distance between the catchment area and the observation point.

A time-averaged concentration was calculated by the method illustrated in Section 3.3.2. To obtain average concentrations, however, the area under the whole curve was divided by the total duration of the event. No division into peak and tail segments was made.

The ranges of average values and maximum concentrations are shown in Table 5. Some concentration maxima were extremely high because of residential construction.

The results in Table 5 illustrates the high event to event variability of pollutant concentrations. Because the developed suburban catchment was 20 percent to 25 percent impervious, rainfall was collected quickly. Usually within one to two hours after the start of runoff flow, pollutant concentrations and flow reached a maximum and then quickly tailed off. Further runoff was relatively pollutant free.

In contrast, agricultural runoff pollutant and flow maxima occurred four to eight hours after the flow started and, because of surface storage, the tail often exceeded 12 hours. An average of the events observed in the study showed that the urban runoff took 5 to 5.5 hours while the agricultural took 24 hours.

3.3.2 Calculation of Pollutant Loadings. The calculation of pollutant loadings was needed to assess the impoundment as a treatment system. Calculation of the loading and the mass discharged was similar and required knowledge of both pollutant concentration and runoff (or effluent) flow with time. The product of concentration and volume gave the mass transported.

The simplest procedure was to calculate a total flow volume and average concentration value for the whole curve by integrating the flow curve and by dividing this value by the event duration. (The same duration had to be used for both curves.) However, it was found that unreasonably low average values were obtained for some curves because of the long duration of the low concentration portion of the curve.

The calculation was improved by dividing the flow curve into two segments: the peak segment, as distinguished from the peak or maximum value, and the tail segment. ("Peak" and "tail" in this report refer to these two segments of plotted curves.)

TABLE 5 RANGE OF CONCENTRATIONS OBSERVED FOR SUBURBAN STORMWATER RUNOFF

	Average Concentration Range	Maximum Concentration Range	Number of Events
Suspended Solids, mg/L	43 - 256	82 - 2000	5
BOD, mg/L	<6	8	1
Total Phosphorus, mg/L	0.12 - 0.47	0.22 - 0.67	6
Organic Nitrogen, mg/L	0.46 - 1.77	1.01 - 4.95	4
Nitrate Nitrogen, mg/L	0.16 - 1.43	1.20 - 2.02	5
Total Coliform, counts/100 mL x 10 ⁻³	13 - 192	34 - 430	4
Fecal Coliform, counts/100 mL	2100 - 6500	4500 - 28 000	4
Fecal Streptococcus, counts/100 mL	25 - >10 000	50 - >33 000	4
Flow, m ³ /s	0.01 - 0.10	0.028 - 1.003	26

The division was at approximately the point of inflection on the receding slope of the flow curve. Plots of all other parameters were divided at the same point in time.

The total volume of flow for peak and tail were found by integrating each segment of the curve. Next, the average concentration for each pollutant was calculated for peak and tail segments by dividing the integrand by the elapsed time of each segment. The product of flow and concentration for each peak and tail were added to arrive at the total mass loading.

The method is illustrated by Figure 26: the first curve represents a typical runoff flow and the second a typical suspended solids curve.

Assume a duration of nine hours, and the point of inflection at three hours. A_1 is the area of the flow peak, A_3 the area of the flow tail. Similarly A_2 is the area of the pollutant peak and A_4 is the area of the pollutant tail.

The average peak concentration was $\frac{A_2}{2.5} = P_2$ and average tail concentration was $\frac{A_4}{6} = T_2$, giving a mass loading of $A_1 P_2 + A_3 T_2$.

3.3.3 Runoff Treatment by Impoundment. The mass of pollutants removed from runoff by temporary impoundment was used to determine the treatment efficiency.

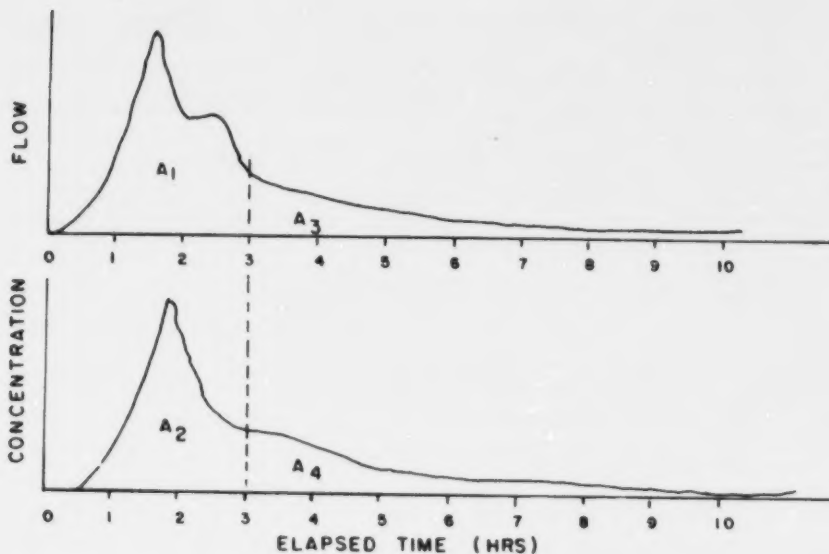


FIGURE 26 FLOW AND POLLUTANT CONCENTRATION CURVES FOR A TYPICAL STORM EVENT

Table 6 presents the concentrations, loadings and percent removals for various parameters. The average concentration values and the loadings calculated for peak and tail are given. For some parameters, especially nitrate and some bacteria, only an average concentration is given because no peak occurred. No distinction was made between agricultural and suburban runoff. For several events, notably August 5 and 13, 1976, and September 18, 1976, runoff was all of suburban origin, sampled at Point 10. The majority of the results were obtained from Sample Point 6, where runoff could be suburban, agricultural or a mixture of both.

No flow data were obtained for the surveys of July 24 and November 21, 1975. Instead, the ratio of runoff to rainfall was used as an approximation of the runoff volume. Thirty-five percent was assumed to be the volume of the flow peak, and was used to calculate the peak and tail loadings. This somewhat arbitrary assumption was based on a computer-generated flow curve for a two-year return, one-hour duration rainfall. In addition, it was found that the peaks of several runoff flows monitored contained from 35 percent to 42 percent of the runoff volume.

The mass transported out of the system was calculated in the same way as influent loading. Effluent parameter curves were uniform in shape, with a rapid rise to a maximum soon after spillway overflow, and a gradual decline to dry weather flow and

TABLE 6 STORMWATER RUNOFF TREATMENT

Parameter and Date of Survey	Influent				Effluent				Influent Peak Loading (% of total loading)	% Removal
	Average Conc. (mg/L)		Loading (kg)		Average Conc. (mg/L)		Loading (kg)			
	Peak	Tail	Peak	Tail	Peak	Tail	Peak	Tail		
<u>Suspended Solids</u>										
July 24/75	967	81.4	6162	435	11.3*		132		93	98
Aug. 5/76	50.4	37.2	32.0	43.8	11.6		21		42	72
Aug. 13/76	366	109	176	25	11.6		8.2		88	96
Sept. 12/75	84.1	15.9	834	293	16	8.9	19.6	20.2	74	96
Sept. 10/76	400	63.5	1482	436					77	
Sept. 18/76	25			549	7.0		227			91
Sept. 21-22/76										
Oct. 21/76	85.3	24.5	339	19	12.4		59		95	84
Oct. 25/76										
Oct. 31/76	145	40.5	63.5	15.5					80	
Nov. 3/76					2		2			97
Nov. 10/75	262	27	1867	357	117	57	834	755	84	29
Nov. 21/75	32.8	4.7	98.5	26.2	5.2	1.6	36.8	21.1	79	54
BOD										
July 24/75	4.3	3.6	27.4	19.2	2.7		32		59	31
Nov. 10/75	3.7	1.8	26	24	2.3		47		52	6

* Where only one value is given, no peak or tail was observed.

TABLE 6 STORMWATER RUNOFF TREATMENT (continued)

Parameter and Date of Survey	Influent			Effluent				Influent Peak Loading (% of total loading)	% Removal
	Average Conc. (mg/L)		Loading (kg)	Average Conc. (mg/L)		Loading (kg)			
	Peak	Tail		Peak	Tail				
<u>Total Phosphorus</u>									
July 24/75	0.46		5.4	0.028		0.3		94	
Aug. 5/76	0.18	0.40	0.11	0.072		0.13	19	78	
Aug. 13/76	0.56	0.34	0.27	0.072		0.05	77	86	
Sept. 10/76	0.58	0.16	2.15				66		
Sept. 18/76	0.110		2.4						
Sept. 21/76				0.124		4.0		29	
Oct. 21/76	0.17	0.14	0.68				86		
Oct. 25/76				0.077		0.4		49	
Oct. 31/76	0.09		0.1	NR*		NR*		-	
Nov. 10/75	0.46	0.14	3.3	0.21	1.9	4	63	23	
Nov. 21/75	0.09		0.8	0.03		0.6		25	
<u>Orthophosphorus</u>									
Nov. 10/75	0.19	0.05	1.4	0.1	0.7	1.9	67	10	
*NR - no result									

*NR - no result

TABLE 6 STORMWATER RUNOFF TREATMENT (continued)

Parameter and Date of Survey	Influent			Effluent			Influent Peak Loading (% of total loading)	% Removal
	Average Conc. (mg/L)		Loading (kg)	Average Conc. (mg/L)		Loading (kg)		
	Peak	Tail		Peak	Tail			
<u>Organic Nitrogen</u>								
July 24/75	3.11	1.73	19.7	9.1	0.42	4.9	68	83
Aug. 5/76	1.94	1.66	1.23	1.96	0.34	0.62	39	81
Sept. 12/75	0.38		7.0		0.57	0.73	0.82	78
Sept. 10/76	1.27	0.39	4.7	2.7			64	
Sept. 18/76	0.44		9.7					
Sept. 21-22/76								
Oct. 21/76	0.37		1.8		0.48	15.6		9
Oct. 31/76	0.34		0.4		NR	NR		-
Nov. 10/75	0.15	0.07	1.1	0.9	0.09	1.8	55	10
Nov. 21/75	0.37		14		0.28	2.0	3.8	59
<u>Nitrate Nitrogen</u>								
Aug. 5/76	1.26	0.62	0.80	0.73	0.84	1.52	52	1
Aug. 13/76	0.73	0.66	0.35	0.15	0.84	0.59	70	-18
Sept. 10/76	0.43	0.21	1.6	1.4			53	
Sept. 18/76	0.35		7.7					
Sept. 21/76					0.05	1.6		85
Oct. 21/76	3.95	2.51	15.7	2.0			89	
Oct. 25/76					2.72	13		27
Oct. 31/76	1.44		0.9					
Nov. 3/76					1.55	1.6		-78
Nov. 10/75	3.23		66		2.9	59		11
Nov. 21/75	1.65	1.68	4.9	9.4	1.30	26	34	-82

TABLE 6 STORMWATER RUNOFF TREATMENT (continued)

Parameter and Date of Survey	Influent				Effluent				Influent Peak Loading (% of total loading)	% Removal
	Average Conc. (counts/100 mL)		Bacteria Loading (counts x 10 ⁹)		Average Conc. (counts/100 mL)		Bacteria Loading (counts x 10 ⁹)			
	Peak	Tail	Peak	Tail	Peak	Tail	Peak	Tail		
Total Coliform										
July 24/75	179 000		20 960		17 900		2 096			90
Aug. 5/76	67 500	47 600	428	561	800		14.5		43	99
Sept. 12/75	103 000	7 943	10 200	1 450	7 000		246		88	98
Oct. 31/76	34 000		277							
Nov. 3/76					1 000		10.6			96
Nov. 10/76	57 000	16 000	4 062	2 118	41 400	21 100	2 953	2 796	66	7
Nov. 21/76	18 000	4 000	538	224	1 000		202		71	73
Fecal Coliform										
July 24/75	2 700	3 300	172	176	720		24.3		49	76
Aug. 5/76	6 300	755	40	9	41		0.7		82	99
Sept. 12/75	2 800	224	277	41	85		30		87	91
Oct. 31/76	600		4.9							
Nov. 3/76					80		0.85			83
Nov. 10/75	4 600	1 000	328	132	3 400	1 500	239	198	71	5
Nov. 21/75	1 000	600	29.8	34.2	84		17		47	73

concentrations. The wide range in pollutant concentration observed in the untreated runoff was not evident for most treated effluent samples. One exception was the survey of November 10, 1975, where the storage volume was displaced in roughly ten hours, with the effluent showing relatively large concentration variations for most parameters.

The treatment efficiency as the percentage of pollutant removed is shown in the last column of Table 6. The results are discussed below in terms of each parameter.

Suspended Solids - Treatment of suspended solids was clearly evident when runoff storage was possible with removals of 84 percent to 98 percent obtained. Where retention time was less than the required 12 hours, i.e. for November 10 and 21, 1975, treatment efficiency was reduced.

Organic Nitrogen - Removal of organic nitrogen appeared to depend on the duration of pond storage and, to some extent, the time of year. Where long storage was possible, some removal took place. Even when the pond was operated as a full system and the retention time was less than 12 hours, some removal was observed.

Nitrate Nitrogen - As indicated by the laboratory settling tests (Section 4) the soluble nitrate compounds were not amenable to treatment by settling. There are indications that nitrates are used as nutrients by algae and aquatic plants, which may explain the 85 percent removal for the survey September 21/76. When plant and algae growth ceased in October and November, the requirement for nutrients decreased, with lower nitrate removal observed. The loss of nitrates from the impoundment observed in November 1975 and 1976 may have resulted from leaching of deposited nitrates, or from decaying organic matter which released nitrate compounds.

Phosphorus and Orthophosphorus - Phosphorus compounds were also difficult to remove by settling. Again algae and aquatic plants were thought to play a large role, but because this nutrient is concentrated in biological growth, it can be carried out of the storage basin by high runoff flows.

Biochemical Oxygen Demand - The biochemical oxygen demand remained relatively low in the 200 samples analyzed. The maximum value was 10 mg/L, with 1 to 5 mg/L most common. Although BOD removal did not appear to take place, the data indicate little or no need for treatment.

Another indicator of the low concentration of organic pollutants was the ammonia nitrogen. This parameter was uniformly found to be less than 0.1 mg/L.

Bacteriological Counts - The total coliform, fecal coliform and fecal streptococcus counts were reduced through impoundment, although data were sometimes difficult to interpret because of continual variations in bacteria densities. Whenever long retention was possible, a reduction in bacteria loading was possible. The mechanism of bacteria reduction was thought to be a combination of adsorption and settling on solid material, dilution in the storage pond, the bactericidal action of algae and through natural dying-off of bacteria during storage. Higher removals were obtained during the summer when algae population was high.

4 LABORATORY STUDY OF POLLUTANT REMOVAL BY GRAVITY SETTLING

4.1 Imhoff Cone Settling Test

Some measure of the rate of settling of pollutants in impounded runoff was desired to obtain the detention time for maximum pollutant removal. During several runoff events, samples of untreated and treated runoff were collected. Portions were placed in six Imhoff cones and permitted to settle for various periods of time. A sample was then withdrawn and analyzed for suspended solids, nitrate nitrogen and total phosphorus. The resulting percentage removal with time is shown in Figure 27.

The (A) curves were derived from the same sample of a highly polluted runoff event November 10-11, 1975. The best removal of suspended solids, phosphorus and nitrogen was approximately 90 percent, 60 percent and 25 percent, respectively. The (B) curves show lesser removal for September 26, 1975 but the initial pollutant concentration was also lower. A partial resuspension took place for each parameter after four to five hours of settling, causing an estimated loss in efficiency of five percent. This indicated that settling in the storage basin should exceed five hours for the best pollutant removal.

The nitrogen and phosphorus pollutants, being soluble anions, were only partly removed, probably through adsorption on suspended solids particles. Phosphorus removal from a treated effluent sample, curve (C), was greater than nitrogen removal from an untreated sample, (curve (A) - Nitrogen, Figure 27).

The greater adsorption, and hence removal of phosphorus, was primarily due to the ionic charge strength of the phosphate ion, although other factors also exerted an influence. The phosphate ion has a charge of -3, while the nitrate ion has a charge of only -1.

Figure 27 shows that gravity settling was effective in removing suspended solids, and to a lesser degree phosphate, but little nitrate removal can be expected.

Comparison of all the curves in Figure 27, indicates that even under laboratory conditions, eight to ten hours were required to achieve maximum settling by gravity alone.

Very little additional settling occurred after 12 hours. In the natural environment of the pilot project settling basin, it would not be possible to prevent mixing from wave action and water currents. Hence, the minimum settling time or hydraulic retention time should exceed twelve hours. At shorter retention times, the treatment efficiency

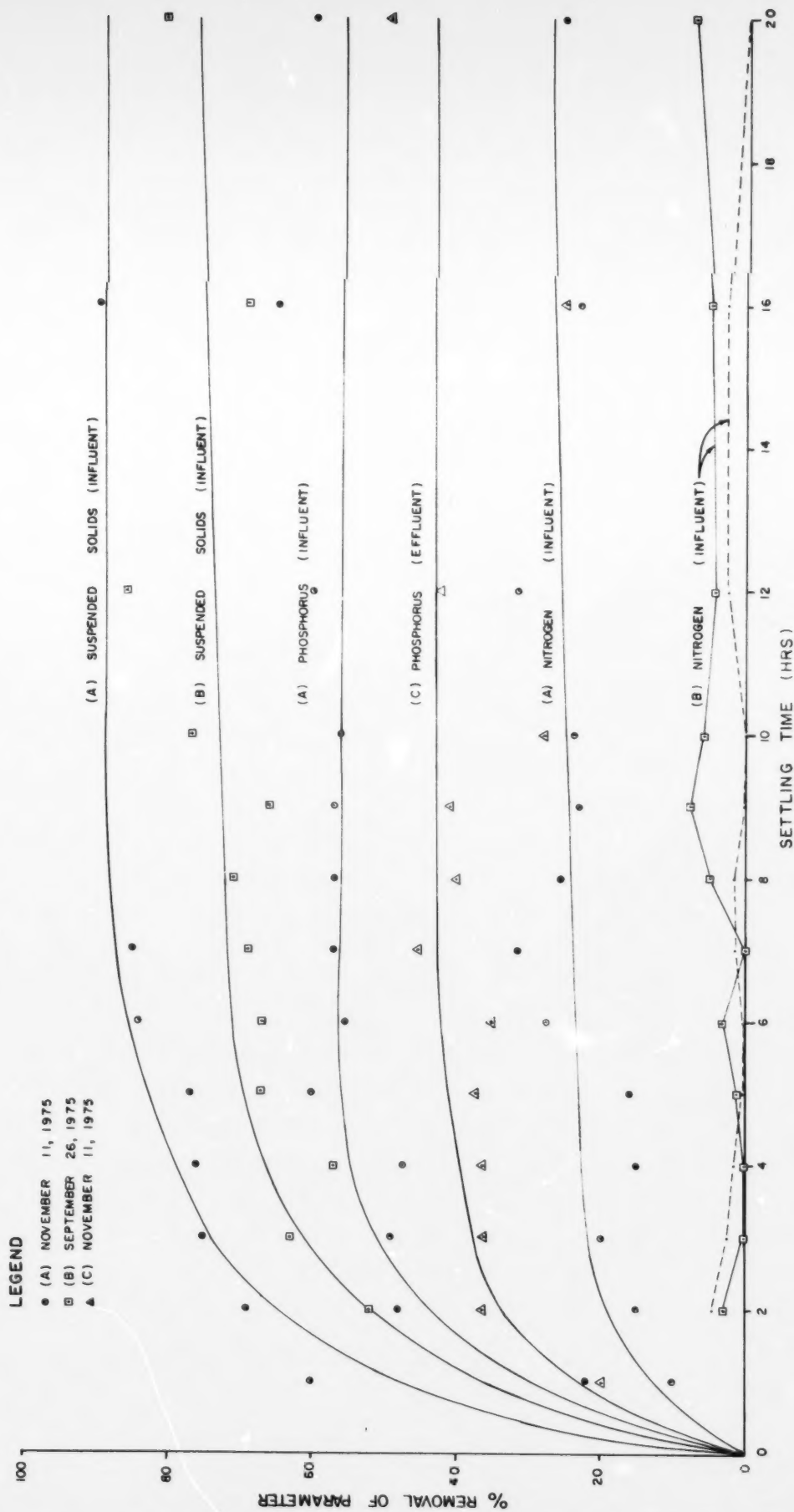


FIGURE 27 LABORATORY STUDY OF SUSPENDED SOLIDS, NITRATE AND PHOSPHORUS REMOVAL BY GRAVITY SETTLING

would be reduced, although in this case the method of operation of the system affects the quality of the effluent.

4.2 Grain Size Analysis of Sediment

Various mechanisms in the gravity settling process promote or hinder removal of pollutants. Larger solid particles quickly settle out while particles of silt and clay remain suspended. Particle size analysis ⁽⁶⁾ of sediment at the pond inlet showed only 5 percent of the deposit having a particle diameter of less than 19 μm . A sample of runoff at the pond inlet indicated that 50 percent of the suspended material was less than 60 μm , and 20 percent was less than 10 μm in diameter. Similar results were obtained for treated effluent at Sample Point 4. These results indicate that little effective settling of particles under 60 μm took place in the pond.

The specific gravity of the solids in suspension was found to vary from 2.56 to 2.69.

4.3 Flocculation by Chemical Addition

Chemical flocculants are used to increase the settling rate of pollutants in wastewater. To examine the applicability of chemical flocculation to pollutant removal in stormwater runoff, and perhaps arrive at a useful dosage range, jar tests were run on samples of polluted creek flow, and treatment pond influent and effluent.

The test was conducted with a rapid mix for three minutes at 100 rpm followed by a slow mix at 25 rpm for three minutes and from five to ten minutes of settling before samples were withdrawn for analysis.

The results indicated that a dosage of alum of 4 to 6 mg/L gave the best treatment of the highly polluted sample. Higher dosages were less effective, with a final suspended solids concentration of 166 mg/L and total phosphorus of 0.45 mg/L at 20 mg/L Al^{3+} . There was no measurable effect on the nitrate concentration. The same result with ferric chloride suggested that excessive dosing of coagulant was as ineffective as under-dosing. Ferric chloride gave the best suspended solids removal. The ferric chloride floc settled more rapidly than the alum floc, (specific gravity 1.008) to produce a treated suspended solids concentration of 8 mg/L. Jar test results are summarized in Table 7.

Several trial additions of aluminum sulphate were made to the runoff flow in the field, giving a clearer definition of the problems involved:

- 1) The constantly changing pollutant concentration made it difficult to feed correct coagulant dosages directly into the runoff.

TABLE 7 CHEMICAL FLOCCULATION OF STORMWATER RUNOFF

Sample	Coagulant	Dosage Range for Maximum Removal (mg/L)	Initial Suspend. Solids Concentration (mg/L)	Initial Phosphorus Concentration (mg/L)	Final Suspend. Solids Concentration (mg/L)	Final Phosphorus Concentration (mg/L)
Polluted Creek Flow	Al ³⁺	4 - 6	798	1.75	62 - 64	0.20 - 0.26
	Fe ³⁺	6 - 8	690	N.A.	8	N.A.*
Pond Influent	Al ³⁺	5 - 10	27	N.A.	2 - 4	N.A.
Pond Effluent	Al ³⁺	8 - 10	25	N.A.	7	N.A.

*N.A. - No analyses

- 2) Low-flow velocity (especially for light runoff) into the system hindered mixing of coagulant and pollutants. This was confirmed by stratification of dyed coagulant solutions added to runoff.
- 3) The slight difference in specific gravity between chemical floc and runoff meant that even light turbulence would hinder floc settling or lead to resuspension.

The addition of coagulants to the environment is potentially harmful. Sulphate and chloride ions, trace metals and acids are part of the flocculant solution and may have undesirable long term effects. The settled chemical floc contains relatively high concentrations of iron or aluminum, and may have to be removed periodically to prevent its being washed out at times of high flow, such as during spring runoff.

An alternative to "on-line" flocculant addition would be "off-stream" storage and treatment of the most concentrated portion of the runoff. Adequate mixing and settling times could be provided and the settled floc retained in the off-stream storage basin. Dosages could be established by jar testing.

The pollutant removal capability for treatment systems may be enhanced by the judicious use of flocculating agents. This, plus off-stream storage, may prove a highly attractive approach to runoff treatment.

5 APPLICATION OF RESULTS TO STORMWATER MANAGEMENT

This study has shown that treatment of runoff by impoundment reduced suspended solids, bacteria and, at times, nutrients. Some of the factors influencing treatment effectiveness can be controlled through design, some through operating methods, and some cannot be controlled. This section summarizes system design considerations and operating procedures relevant to the Barrhaven site, and discusses their application to general stormwater management in the vicinity of the Rideau River.

5.1 Design Considerations for the Permanent Treatment System

Design of an impoundment for stormwater treatment must consider: frequency of runoff events, volume of runoff produced, method and rate of discharge of treated runoff, and treatability of pollutants by settling. Most important, perhaps, is the storage volume.

5.1.1 System Storage Volume. Unless the Madden Award Drain were rerouted, the permanent treatment system will have to deal with both storm sewer and agricultural drainage. Expected runoff volumes for several intensities and durations of storm were calculated and are given in Table I, Appendix II. A two-hour duration 25-year frequency storm would require 57 000 m³ of storage for complete containment. However, since the full storage volume would be used only four times in 100 years, the cost may not be justified. Containment of runoff from a ten-year storm of two hours duration would require 47 000 m³ and provide runoff treatment 90 percent of the time.

The gradual slope of the ravine created other problems. A filled treatment reservoir of 57 000 m³ would submerge the outfall of the storm sewer and cause it to back up several hundred meters. For at least several days, the system would be unable to provide treatment for moderate runoff flows, especially overland runoff. In addition, there would be a high risk of property damage from flooding.

The choice of a storage volume of about 43 000 m³ would contain runoff from storms of somewhat less than a 10-year return frequency (two-hours duration), or slightly less than 90 percent of the events in any year. The rate of discharge of treated effluent must also be considered.

5.1.2 Treated Effluent Discharge Rate. An excessive rate of discharge will result in transport of deposited solids and increased bank erosion downstream. Discharge rates could be limited to about twice the dry-weather flow. Where a high rate of discharge is

necessary but dry-weather flow is too low, treated effluent could be conducted by a sewer pipe to the receiving water.

For the small stream studied, dry-weather flow was about $0.057 \text{ m}^3/\text{s}$. Assuming that a flow of $0.113 \text{ m}^3/\text{s}$ would avoid erosion, it would take 4.5 days to drain an impoundment of $43\,000 \text{ m}^3$.

Two other factors will influence or limit the permissible discharge rate: the treated effluent loading rate on the receiving stream, and the time interval available to carry out the treatment cycle (Section 5.2). It is clear that the treated effluent discharge rate may be severely limited by its effect on the receiving water, both in terms of flow increase and reduction of water quality.

5.1.3 Off-Stream Storage of Peak Flow. This refers to abstraction and containment of the most highly polluted part of the runoff, leaving the lightly polluted tail portion without treatment. The flow peak bears from 50 percent to 90 percent of the pollutant loading in about 35 percent of the runoff flow (Table 6). Advantages of off-stream storage would be:

- 1) maximum residence time of the most highly polluted segment of the runoff,
- 2) the most suitable system for chemical flocculation and sludge removal, with least risk of harm to the environment,
- 3) controlled release of the treated runoff whenever its effect on the receiving water would be minimal,
- 4) a significant reduction in storage volume requirement (and capital cost) compared with complete containment.

For the study catchment, off-stream storage would reduce the proposed volume from $47\,000 \text{ m}^3$ to about $16\,900 \text{ m}^3$. The stored runoff could be released at $0.098 \text{ m}^3/\text{s}$, approximately twice the dry-weather flow of the existing drainage stream.

At the Barrhaven site, off-stream storage could be accomplished by constructing a second dam downstream of the existing one and by providing a bypass conduit around the storage volume between the two dams.

To summarize:

- 1) storage capacity should be sufficient to contain $47\,000 \text{ m}^3$ of runoff,
- 2) treated runoff discharge rate should empty the system in 48 hours, but without causing downstream erosion,

- 3) if off-stream storage of the first flush is used, a capacity of only 17 000 m³ would be needed,
- 4) the design should provide for batch runoff treatment with one day to fill, one day storage and two days to discharge.

5.2 Treatment System Operation

Operation of the pilot system was in both a batch ("fill and dump") mode and in the continuous flow-through mode. Important in assessing these methods is the frequency of occurrence of rainstorms which produce runoff (i.e., rainfall >5 mm). This directly affects effluent release rates, and governs the duration of the batch treatment cycle.

5.2.1 Treatment System Operating Cycle. The frequency of rainfall events of less than 5 mm accumulated rainfall was determined from Ottawa International Airport weather records for 1967 to 1976 ⁽⁴⁾. No attempt was made to characterize rain events as to return period (i.e., intensity and duration), nor to consider the effect of antecedent rainfall <5 mm. The period analysed was from April to November.

The results of this analysis are presented in Appendix II, Figures II.4 and II.5, and Table II.3, and are summarized here:

- a) from April to November, the average interval between rainfall events was 6.5 to 7 days;
- b) there was little variation in frequency of occurrence from April to November, or in the period when swimming beaches are used, June to September;
- c) 50 percent of rainfall events (i.e., runoff events) occur within four days or less, of one another.

To capture runoff from at least half the rainfall events, the treatment system should take no more than four days to process runoff. With a longer treatment cycle, a second runoff flow would almost certainly overload the system.

The study showed that a 24-hour period was usually sufficient for runoff capture, and that 24 hours' quiet settling will provide maximum pollutant removal. Treated effluent can be released over the last two days of the cycle. There is a 30 percent probability that there will be another runoff flow before release of treated runoff begins.

The requirement for a two-day release period and the need to avoid downstream erosion place severe limitations on the release rate. For the proposed storage volume of 47 000 m³, the 48-hour discharge rate would be 0.272 m³/s, almost five times

the dry-weather flow. This rate has been observed to cause recontamination in the stream being studied.

Again, off-stream storage or providing an effluent sewer may be solutions.

5.2.2 Continuous-Flow Operation. In 1975 the system was operated as a constantly full basin with continuous overflow, and performed with the following characteristics:

- a) pollutants passed through the system in peaks, though reduced in concentration and much broader, with little mixing of peak and tail;
- b) pollutant residence time was a function of the runoff flow rate;
- c) two runoff events close together resulted in pollutants from the first being washed out with reduced treatment;
- d) the full reservoir had a greater population of biota and should be more efficient in removing bacteria and soluble nutrients;
- e) there was little operational control possible over effluent quality; i.e., treatment efficiency is predetermined by the design of the system rather than by how it is operated.

A modified continuous-flow operation could reduce or eliminate some of these problems. At the start of a runoff event or a rainfall, unpolluted water already in the pond could be discharged. Discharge could be continued until the water quality reached the limit permitted, providing the maximum residence time. This method would require an operator.

A serious difficulty with continuous-flow operation is the lack of control over the discharge rate. The full pond will discharge whatever flow enters, regardless of its effect downstream.

5.2.3 Batch On-Stream Operation. The batch treatment process operated with the following characteristics:

- a) runoff peak and tail were well mixed;
- b) pollutant residence time was a function of storage volume;
- c) two runoff events close together will not reduce the treatment of the first runoff, since it will have had the maximum residence time;
- d) the population of pond biota will be small compared with a continuously full reservoir;
- e) an operator may be required to drain the reservoir;
- f) discharge may be governed by effluent quality.

Batch operation will result in mixing and dilution of the peak and tail, so that even when the runoff volume exceeds the storage capacity, the effluent concentration will be uniform. Pollutants will thus be discharged to the Rideau River at the lowest possible concentration and at the slowest possible rate.

Batch treatment operation will probably require an operator, although automated equipment or telemetry can be used. Sampling of the effluent and equipment maintenance will require visits to the site.

Considering the merits of both methods, batch on-stream operation provided the longest possible residence time for a given flow, and provided for controlled discharge of treated effluent.

A more quantitative assessment of batch versus continuous-flow operation could be made by comparing the degree of pollutant removal from runoff generated by similar rainstorms under each method.

5.3 Stormwater Treatment and Water Management

Rapid suburban growth and land development create a need for stormwater treatment systems where it is imperative to maintain the quality of major water courses. The Rideau River, or its tributary the Jock River, at this time has three other stormwater treatment systems nearing completion and one being designed. Extensive runoff treatment is being planned for a large urban community of 100 000 on the Rideau River directly south of Barrhaven. These treatment systems cannot be considered independent of each other since effluent from one system will alter the quality of the river water and affect the operation of treatment systems downstream.

Treatment of runoff must be approached on a whole watershed basis. In the case of the Rideau River, which originates outside the boundaries of the Regional Municipality of Ottawa-Carleton, the following should be established:

- 1) a policy setting out the pollution budget for each tributary, which would define the extent of treatment required;
- 2) a standard of water quality for reaches of the Rideau River from Kemptville to the Ottawa River, which would include maximum permissible loading rates of pollutants for each reach, and would define the extent of stormwater treatment required.

A bacteriological standard for swimming areas has been set, and a limit of 4 mg/L biochemical oxygen demand for tributary flows has been set by the Ministry of the Environment.

The discharge of treated runoff from several systems must be coordinated so that their combined effect does not cause the Rideau River water quality to fall below the standard. The rate of discharge of treated effluent can be determined either by the maximum permissible loading rate on the receiving stream, or by the discharge rate required to empty the reservoir within the time required by the frequency of runoff event occurrence. Since half the runoff events will occur within four days of one another, a maximum discharge time of two days is suggested. For large drainage areas this may require several small ponds rather than a large one.

Runoff treatment systems must be designed and operated to meet the overall objectives of water quality management in the Rideau River. This can be done only with establishment of realistic standards of runoff treatment and with a coordinated water management program for the Rideau River watershed.

It should be noted that, during the revision of this report, the Ministry of the Environment set the following criteria for stormwater detention pond effluent:

BOD	5.6 mg/L
Total phosphorus	1.0 mg/L
Total chlorine residual	0.1 mg/L
Total coliform	1 000 counts per 100 mL
Fecal coliform	100 counts per 100 mL
Fecal streptococcus	20 counts per 100 mL
Suspended solids	no standard; one may be set if necessary.

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APPENDIX I:
RATING CURVES
FOR FLOW MEASURING SYSTEMS



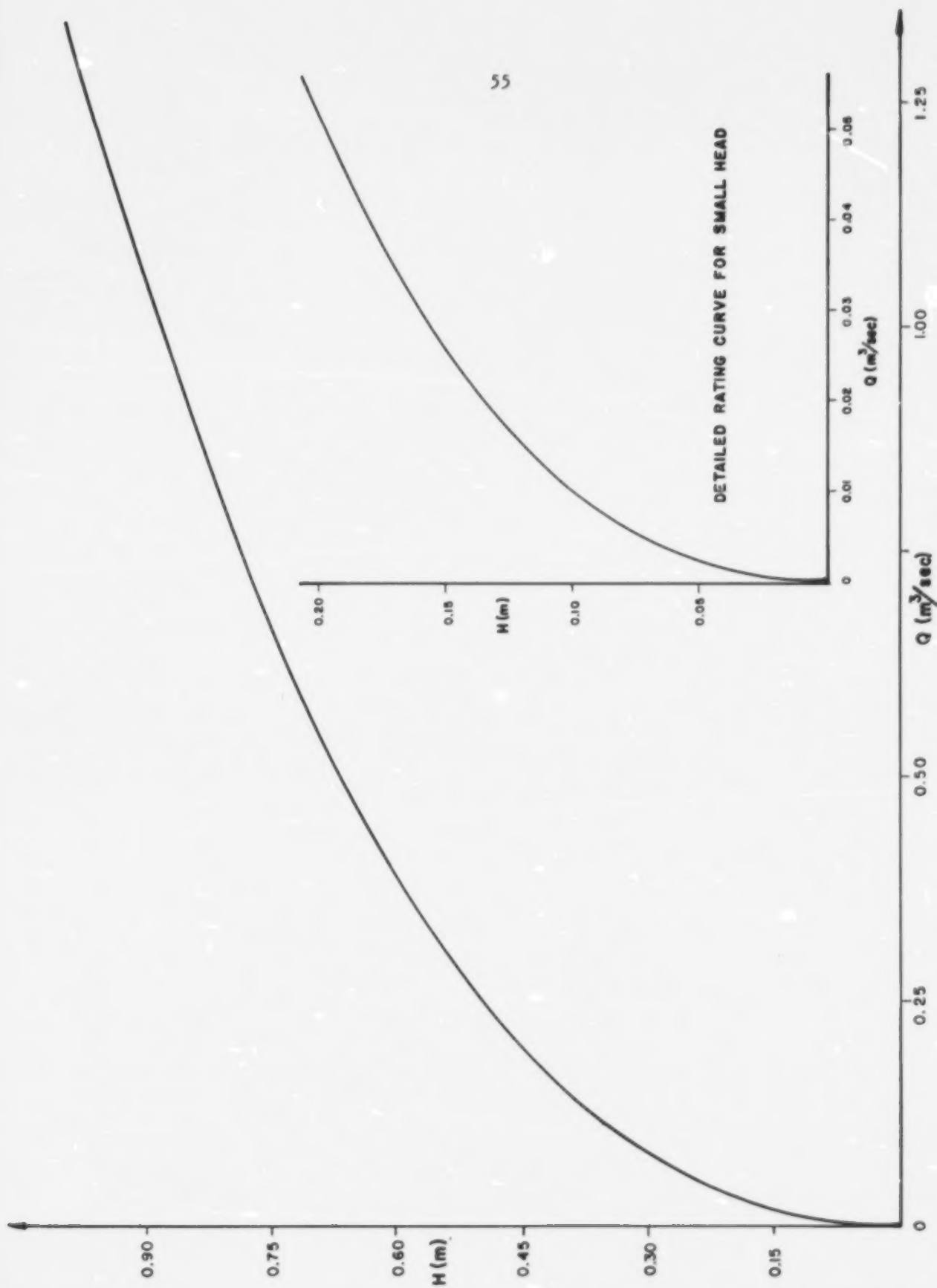


FIGURE I.1 RATING CURVE FOR 90° V-NOTCH SHARP EDGED WEIR

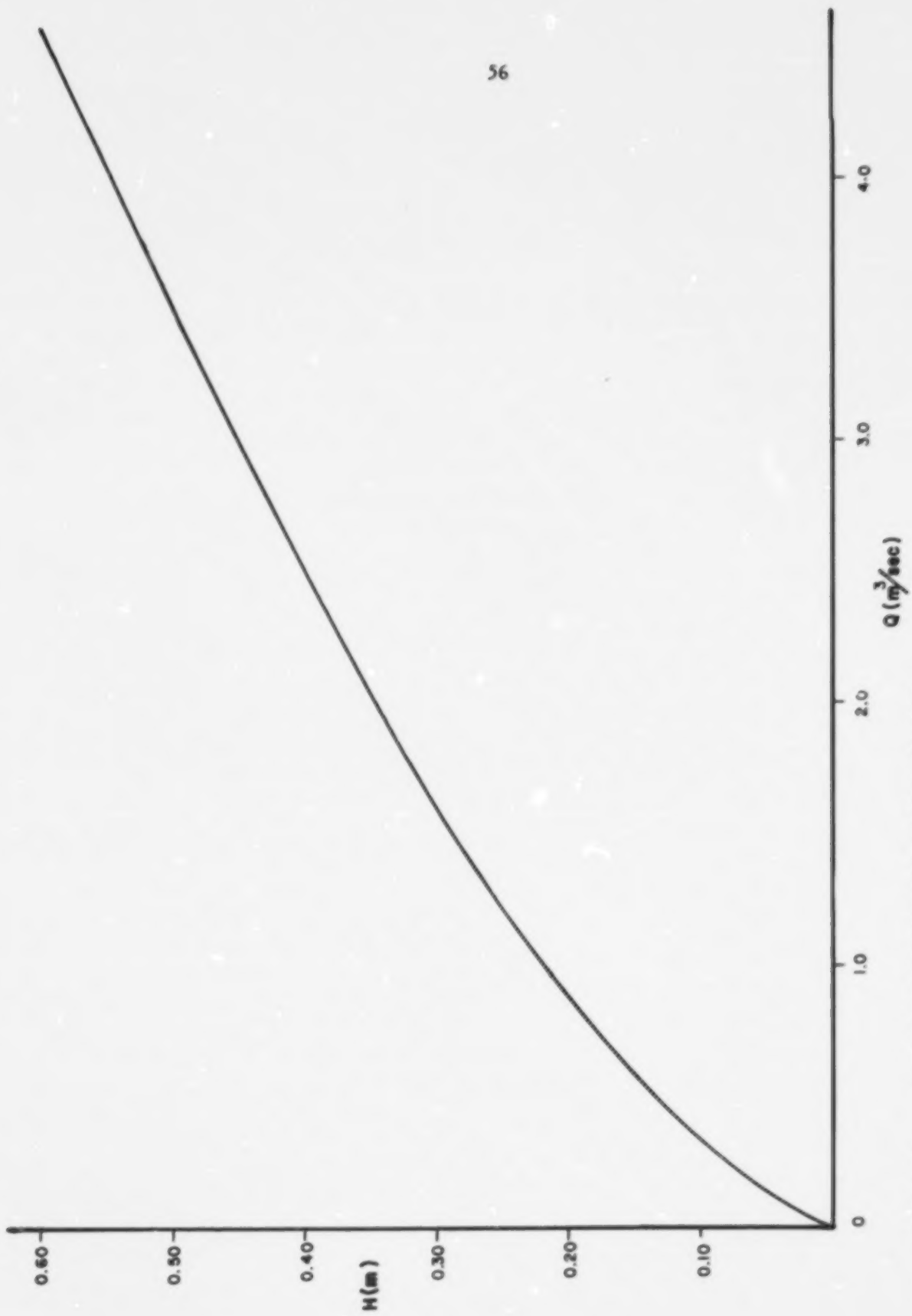


FIGURE I.2 SPILLWAY DISCHARGE RATING CURVE

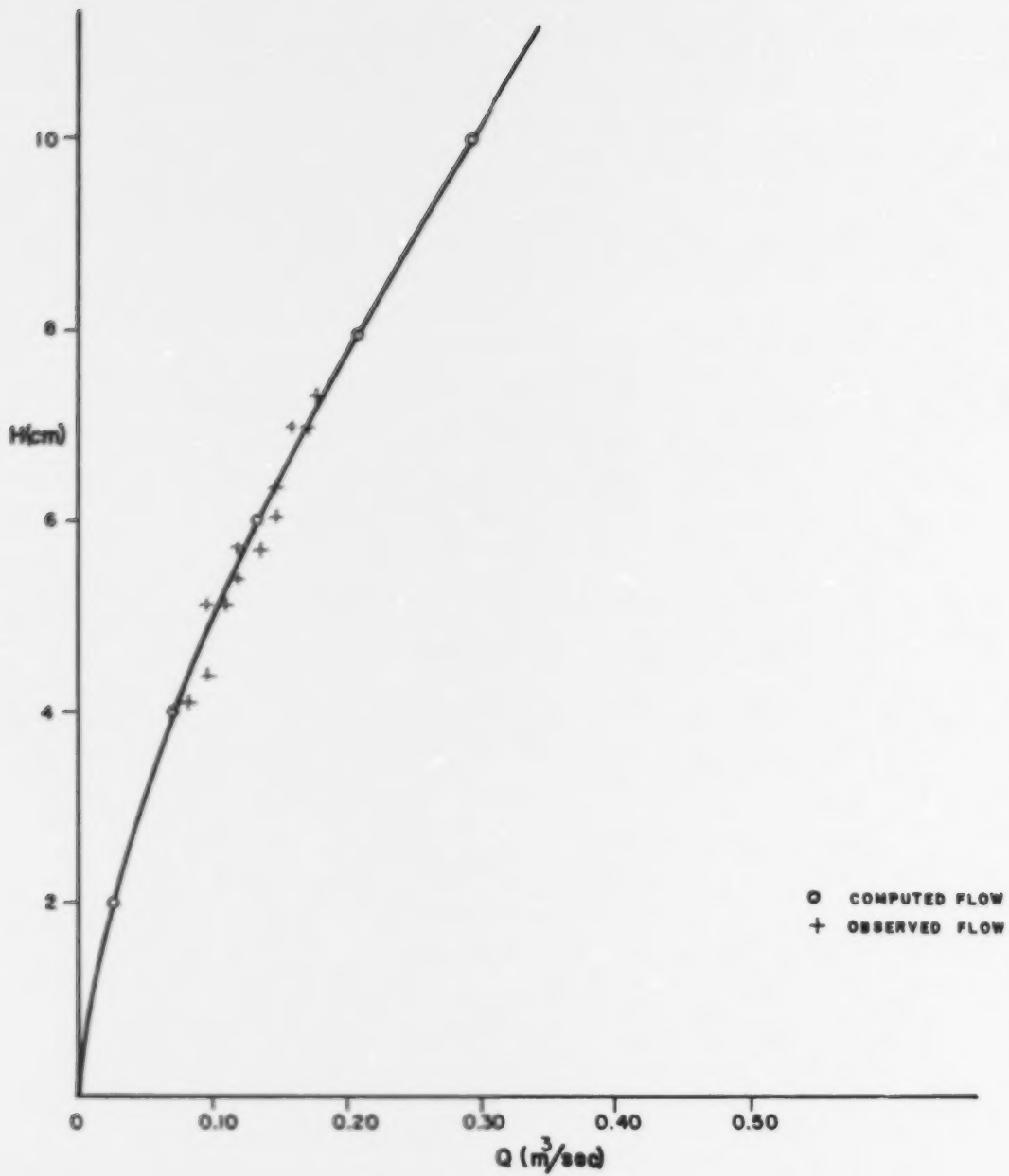


FIGURE 1.3 CALIBRATION OF SPILLWAY AT LOW FLOW

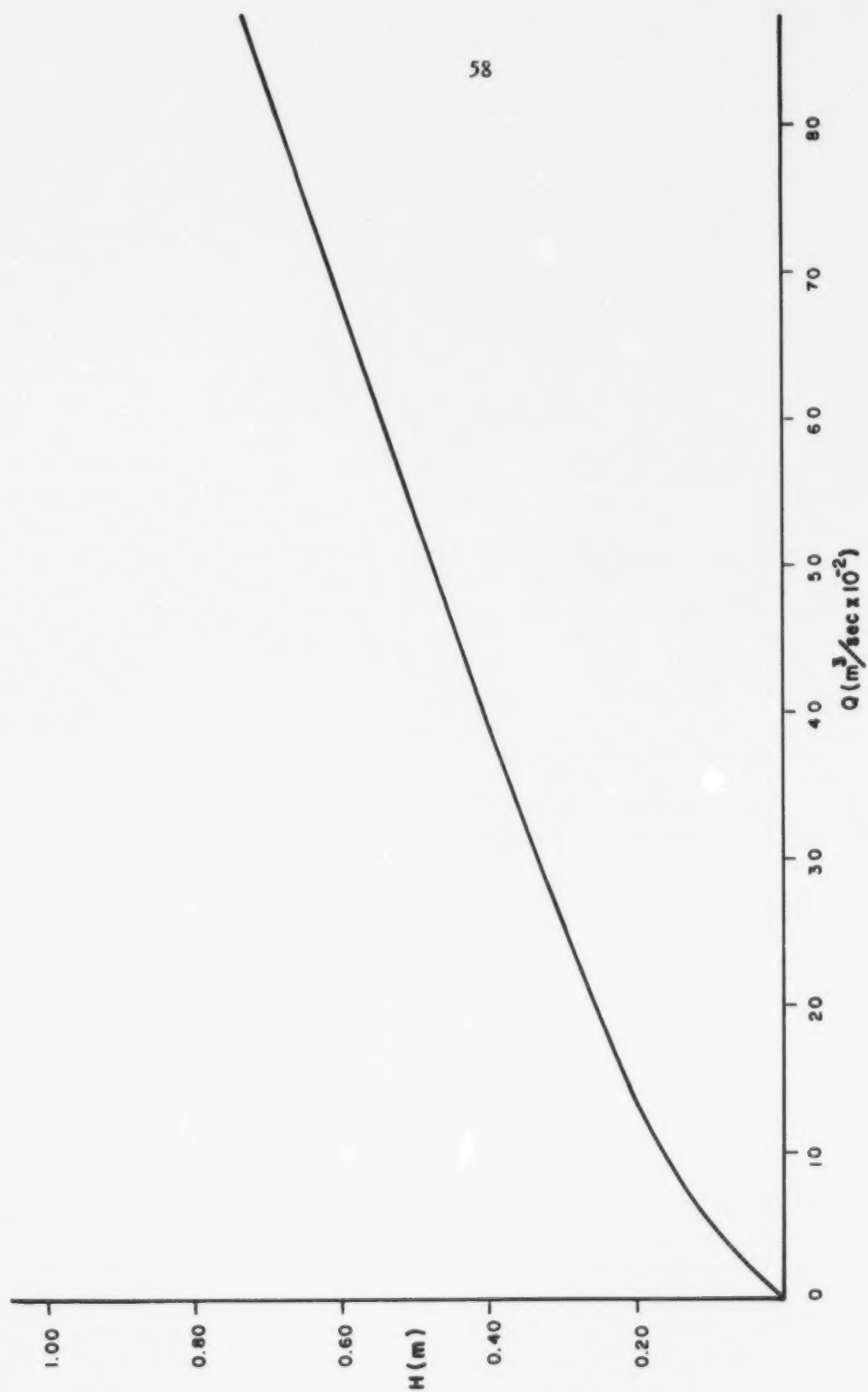


FIGURE I.4 DISCHARGE OF 27.4 CM OUTFALL

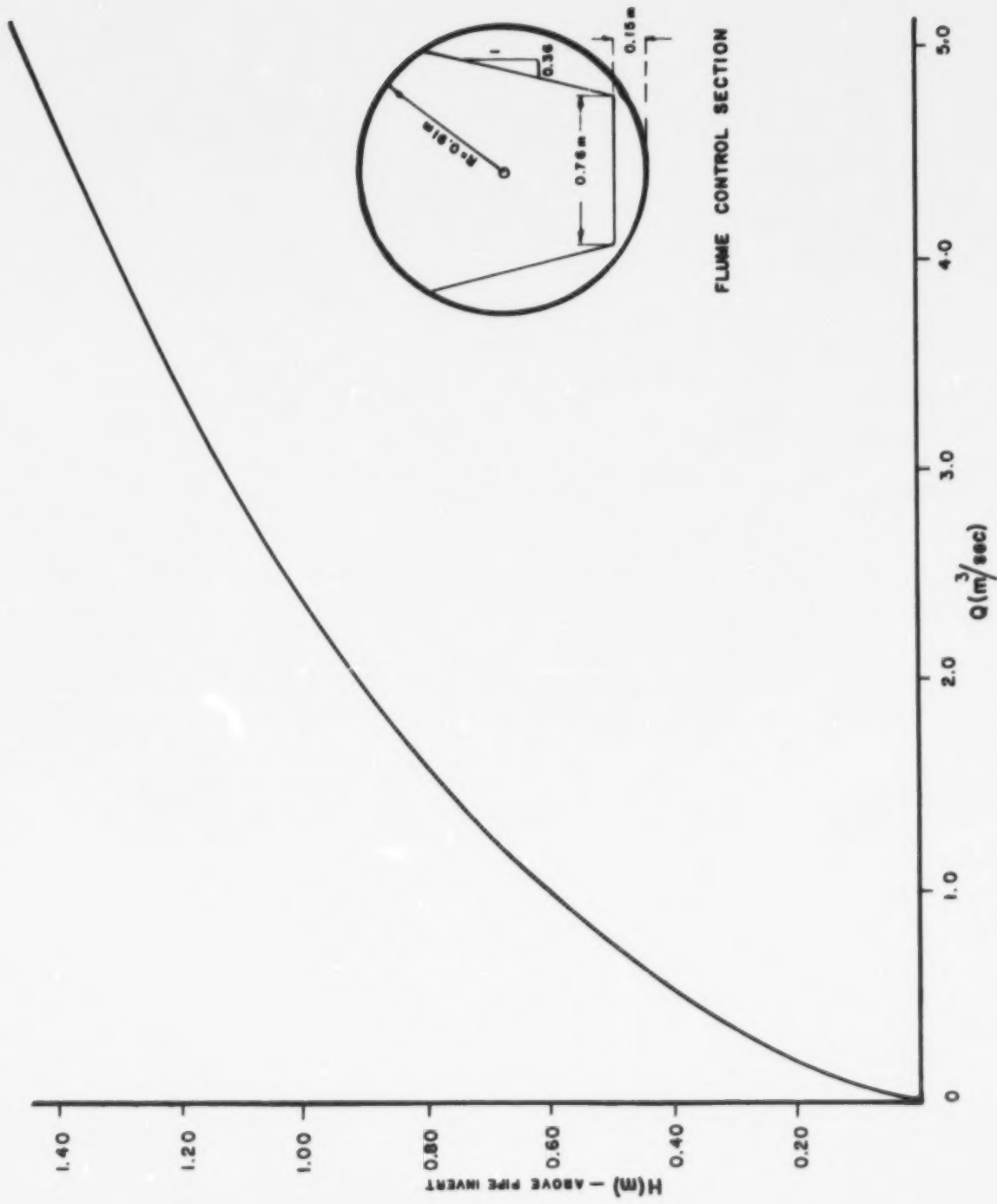


FIGURE 1.5 RATING CURVE FOR PALMER-BOWLUS FLUME



APPENDIX II:
RAINFALL AND VOLUME
OF RUNOFF PRODUCED



APPENDIX II: Rainfall and Volume of Runoff Produced

The volume of runoff associated with a particular rainfall was determined through the empirical establishment of a runoff to rainfall ratio.

Runoff volume was measured at the Palmer-Bowlus flume, (Sample Point 10) and the total accumulated rainfall was measured by either on-site rain gauges or rainfall data from Ottawa International Airport. Developing a ratio which would be generally applicable is made difficult by the effect of antecedent rainfall. It saturates the soil and fills surface depression storage, so a light rainfall event could generate as much runoff as a very heavy rainfall preceded by a long dry spell.

Of the 20 runoff events observed in 1976, eight were preceded by at least four rainless days. A least squares fit to the points gave the curve A shown in Figure II.1. The ratio of runoff to rainfall was 0.133. Using all the data, regardless of antecedent conditions, gave a ratio of 0.138, a difference of less than 0.5 percent, with a total estimated error of 10 percent. Two events which were very short and with intense rainfall, or which were directly preceded by heavy rainfall, were omitted. In these, the runoff came in two peaks, with the second being the heavier. The first peak had eliminated the antecedent effect, resulting in a ratio of runoff to rainfall from the second peak of 0.244 to 0.250.

From Figure II.1, runoff begins only after some $6\,000\text{ m}^3$ of rain had fallen. An accumulated rainfall of 5 mm is required before runoff begins, assuming a uniform rainfall pattern over the catchment area.

About half of the 99 ha drainage area was semi-developed. The soil surface here was similar to that expected in a ploughed and harrowed field, although paved streets and rooftops in the developed portion created a much higher percent impervious area.

Table II.1 gives the calculated runoff volumes for storms of both one and two hours duration and various return frequencies. The runoff volume has been calculated for both drainage areas.

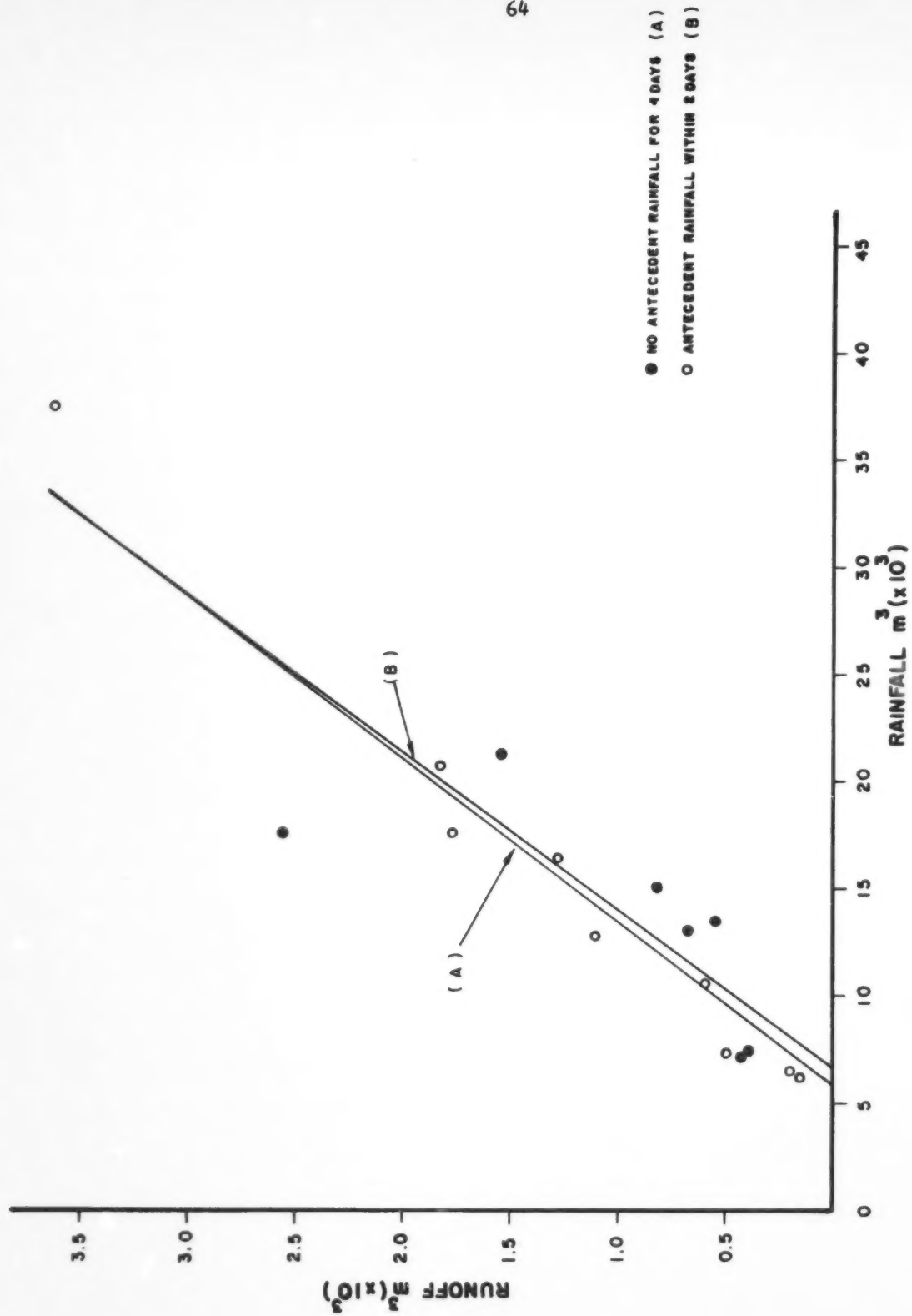


FIGURE II.1 RUNOFF AS A FUNCTION OF RAINFALL IN THE BARRHAVEN AREA

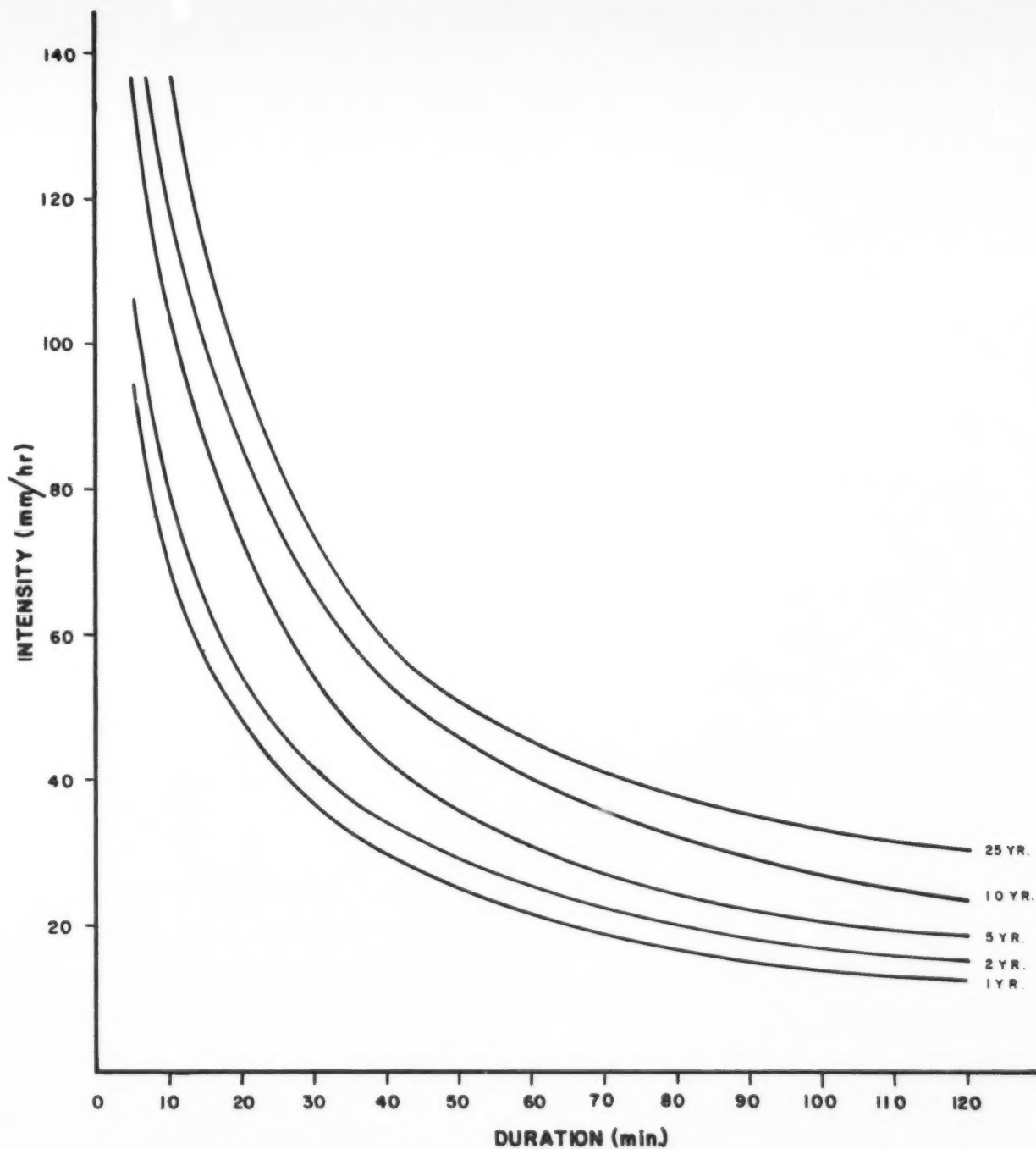


FIGURE II.2 RAINFALL INTENSITY DURATION CURVES
(BASED ON DATA FOR 21 YRS FROM OTTAWA EXPERIMENTAL
FARM)

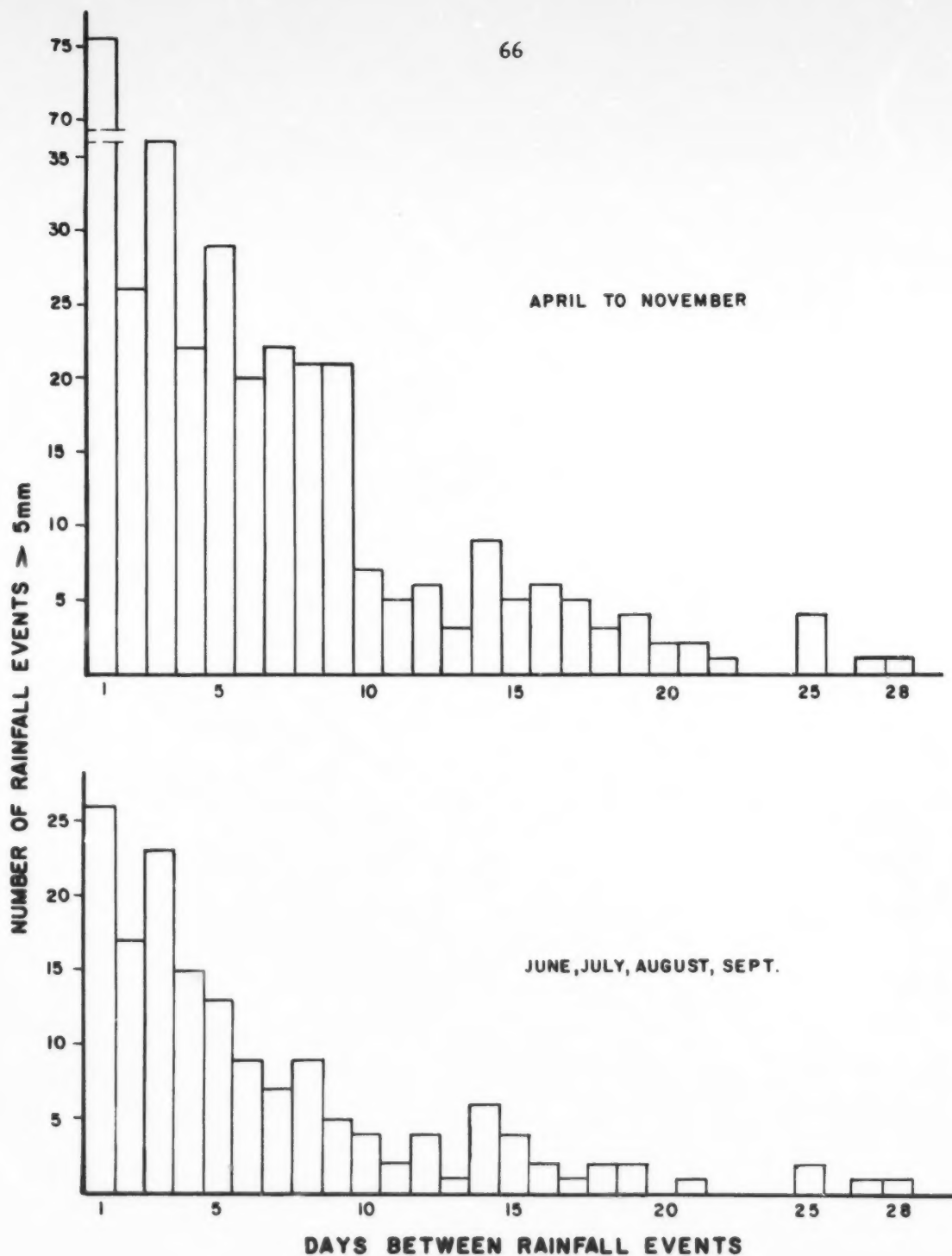


FIGURE II.3 FREQUENCY OF OCCURRENCE OF RAINFALL EVENTS > 5mm

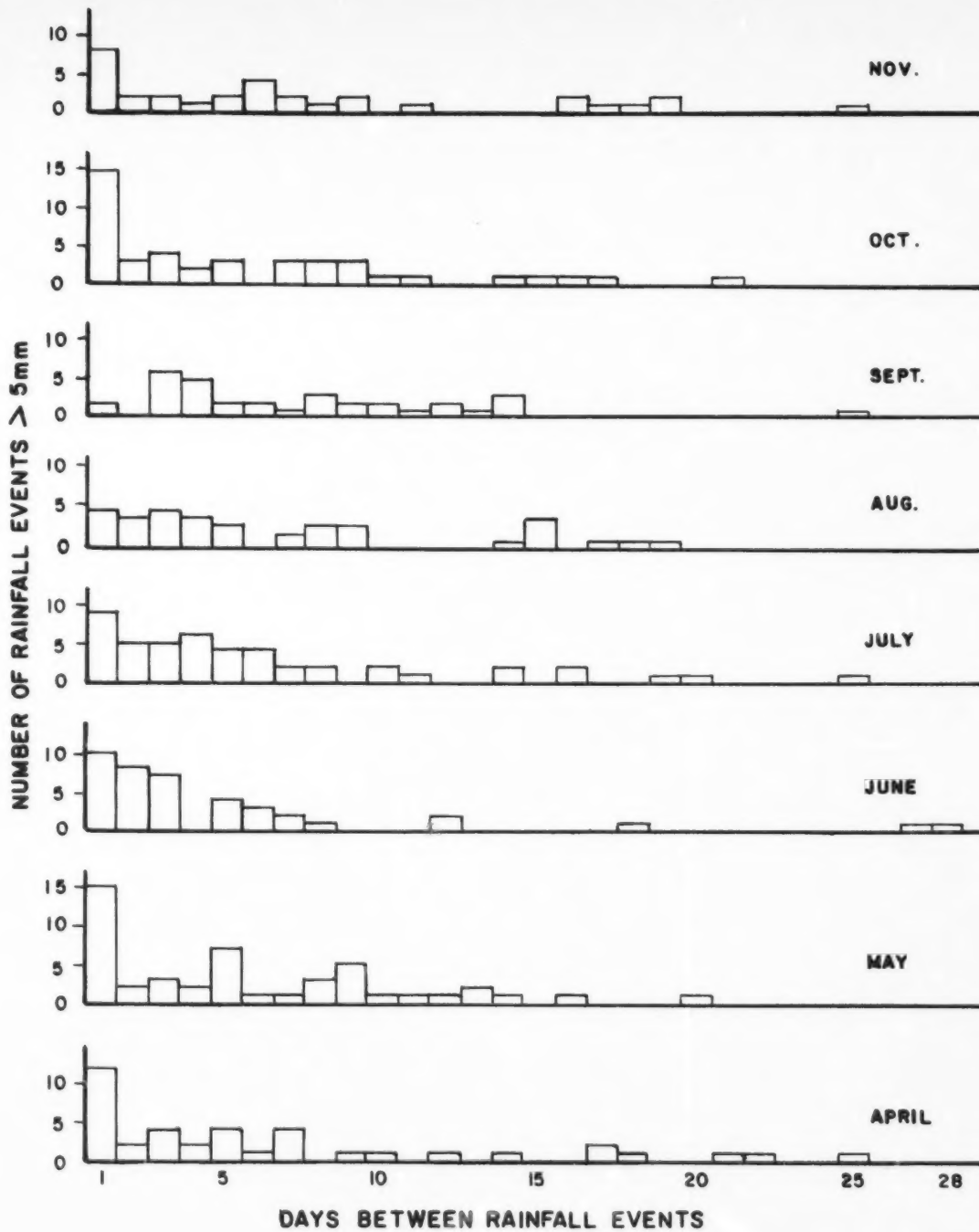


FIGURE II.4 MONTHLY FREQUENCY OF OCCURRENCE OF RAINFALL EVENTS >5mm

TABLE II.1 RUNOFF GENERATED BY VARIOUS RAINSTORMS

Storm Return Frequency	Rainfall Intensity (mm)		Runoff Volume for Drainage Area (m ³)			
			1-h Duration		2-h Duration	
	1 h	2 h	121 ha	866 ha	121 ha	866 ha
1 yr.	21.3	12.7	2 560	18 400	3 210	23 000
2 yr.	24.9	14.7	3 130	22 400	3 840	27 500
5 yr.	31.8	19.1	4 220	30 200	5 220	37 400
10 yr.	40.6	23.4	5 600	40 100	6 580	47 100
25 yr.	45.7	27.9	6 400	45 800	7 990	57 200

Runoff to rainfall ratio used - 0.13.

Volumes shown allow for first 5 mm being absorbed.

TABLE II.2 COMPARISON OF RAINFALL AT OTTAWA INTERNATIONAL AIRPORT AND CENTRAL EXPERIMENTAL FARM

Month	Ottawa International Airport			Central Experimental Farm		
	Average Rainfall 1939-1975 (mm)	Rainfall for 1975 (mm)	% of Past Average Rainfall	Average Rainfall 1940-1970 (mm)	Rainfall for 1975 (mm)	% of Past Average Rainfall
Jan.	13.7	18.0	131.4	16.0	ND*	ND
Feb.	11.1	11.7	105.4	13.0	ND	ND
Mar.	27.1	51.8	191.1	27.4	ND	ND
Apr.	56.2	9.1	16.2	60.7	8.9	14.7
May	69.9	59.2	84.7	68.6	43.9	64.0
Jun.	74.2	48.3	65.1	74.2	67.3	90.7
Jul.	86.4	150.6	174.3	81.0	108.2	133.6
Aug.	79.1	29.2	36.9	86.4	26.7	30.9
Sep.	76.5	127.0	166.0	81.8	96.0	117.4
Oct.	63.9	66.9	104.7	65.5	75.4	115.1
Nov.	55.9	67.7	121.1	59.4	ND*	ND
Dec.	29.4	33.5	113.9	28.5	ND	ND
Rainfall for 1976				Rainfall for 1976		
Jan.	13.7	14.5	105.8	16.0	ND	ND
Feb.	11.1	28.9	260.4	13.0	ND	ND
Mar.	27.1	52.2	192.6	27.4	ND	ND
Apr.	56.2	48.5	86.3	60.7	43.9	72.3
May	69.9	90.5	129.5	68.6	111.5	162.5
Jun.	74.2	73.6	99.2	74.2	123.7	166.7
Jul.	86.4	28.1	32.5	81.0	75.9	93.7
Aug.	79.1	78.3	99.0	86.4	81.3	94.1
Sep.	76.5	95.7	125.1	81.8	113.8	139.1
Oct.	63.9	70.7	110.6	65.5	83.8	127.9
Nov.	55.9	19.6	35.1	59.4	ND	ND
Dec.	29.4	3.8	12.9	28.5	ND	ND

*N.D. - No data recorded at experimental farm for these months.

TABLE II.3 CUMULATIVE PERCENT OF RAINFALL EVENTS >5mm

Time Period	Number of Days Separating Events														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
April to November	23.9	32.1	43.4	50.3	59.4	64.2	69.5	74.5	79.6	81.8	83.3	85.2	86.2	89.0	90.6
June to September	16.6	27.4	42.0	51.6	59.9	65.6	70.0	75.8	79.0	81.5	82.8	85.3	86.0	89.8	92.4
April	30.8	35.9	46.1	51.3	61.5	64.1	74.3	74.3	76.9	79.5	79.5	82.1	82.1	84.6	84.6
May	32.6	37.0	43.5	47.8	63.0	65.2	67.4	73.9	82.6	84.8	87.0	89.1	93.5	95.7	95.7
June	25.0	45.0	62.5	62.5	72.5	80.0	85.0	87.5	87.5	87.5	87.5	92.5	92.5	92.5	92.5
July	19.1	29.8	40.4	53.2	61.7	70.2	74.5	78.7	78.7	83.0	85.1	85.1	85.1	89.4	89.4
August	13.5	24.3	37.8	48.6	56.8	56.8	62.2	70.3	78.4	78.4	78.4	78.4	78.4	81.1	91.9
September	6.1	6.1	24.2	39.4	45.5	51.5	54.5	63.6	69.7	75.8	78.8	84.8	87.9	97.0	97.0
October	37.5	45.0	55.0	60.0	67.5	67.5	75.0	82.5	82.5	83.4	85.0	85.0	85.0	90.0	92.5
November	25.8	32.3	38.7	41.9	48.4	61.3	67.7	71.0	77.4	77.4	80.6	80.6	80.6	80.6	80.6

TABLE II.4 RAINFALL SURVEY 1976

Date	Start Time (h)	Duration (h)	Time of Maximum Intensity (h)	Total Accumulation (mm)	Total Vol. on Drainage Area (m ³)	Intensity (mm/h) Avg.*	Freq.**
June	8/76	16:40	0:20	16:45	12.2	14 800	36.6
	11/76	05:45	4:15	08:15	4.3	5 200	1.0 5.8 1 yr
		13:45	0:30	13:45	6.1	10 800	12.2
	14/76	19:00	1:30	19:20	5.3	6 500	3.5
	16/76	13:15	0:45	13:25	17.5	21 300	23.3 9.4 1 yr
	20/76			13.5	16 300		
	24/76	15:35	0:05	15:35	1.5	1 800	18.0
		16:55	0:15	16:55	1.3	1 500	5.2
		23:55	5:20	3.3	4 000	0.6	
July	11/76	15:00	0:45	15:30	6.1	7 400	8.1
	12/76	20:10	1:50	21:50	4.1	6 500	2.2
	16/76	15:45	0:15	15:45	5.8	7 100	23.2 3.8 1 yr
Aug.	12/76	13:35	1:15	14:15	5.8	7 100	4.6
		19:25	0:30	19:40	2.8	3 400	5.6
	13/76	08:50	3:00	10:10	6.8	8 300	2.3
		17:45	1:15	18:05	3.6	4 300	2.9
	28/76	17:55	0:45	17:15	14.5	17 600	19.3 10.2 1 yr
		19:30	2:45	19:30	13.5	16 300	4.9
Sept.	10/76	06:30	2:50	07:50	11.2	13 600	4.0 4.8 1 yr
	18/76	01:55	2:35	02:00	13.7	16 700	5.3 5.6 1 yr
		13:55	2:30	14:40	3.3	4 000	1.3 5.3 1 yr
	20/76	00:35	17:45	14:20	32.5	43 500	1.8
	26/76	14:50	8:10	18:20	10.7	12 900	1.3
Oct.	20-21				30.7	37 300	
Nov.	26-27				14.5	17 600	
Oct.	30-31	23:15	13:25	11:00	12.4	15 100	0.9

* Average rainfall intensity at $t_c = 90$ minutes

** From Figure II.1.

TABLE II.5 RUNOFF SURVEY 1976

Date		Start Time (h)	Duration (h)	Time of Maximum Intensity (h)	Total Volume Runoff (m ³)	Peak Flow (m ³ /h)	Runoff/Rainfall Ratio
June	8/76	17:00	2:30	17:10	150	280	.010
	11/76	10:00	3:00	10:30	320	380	.061
		15:00	7:00	15:20	2 640	3 260	.244
	14/76	20:30	2:00	20:45	130	380	.020
	16/76	14:40	5:20	15:00	1 500	2 900	.070
	20/76	16:00	7:30	16:20	1 280	1 420	.078
	24/76	16:50	2:10	17:10	200	351	.111
		18:20	4:10	18:50	130	190	.087
		02:15	7:45	02:55	160	100	.040
July	11/76		3:00		390	790	.052
	12/76	22:50	3:30	00:10	190	180	.028
	16/76	16:50	2:40	17:05	420	900	.059
Aug.	12/76	16:30	4:00	17:00	340	350	.048
		20:45	2:15	21:00	240	330	.070
	13/76	11:15	4:15	11:30	700	440	.084
		18:45	3:00	19:15	400	440	.093
	28/76	19:35	2:25	19:50	1 800	3 470	.102
		22:30	4:00	23:00	770	610	.047
Sept.	10/76	08:30	4:10	09:10	530	800	.039
	18/76	03:40	3:50	04:15	840	880	.050
		15:30	6:00	16:20	1 000	530	.250
	20/76	03:00	19:00	16:00	2 780	500	.064
	26/76	18:15	9:00	19:50	680	150	.053
Oct.	20-21				3 610	670	.097
	30-31	09:00	8:15	11:30	820	190	.054
Nov.	26-27	14:15	26:30	17:45	1 780	370	.101